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1989 Report to the Congress on the

Strategic Defense Initiative

March 13, 1989

Prepared by the Strategic Defense Initiative Organization

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THE SECRETARY OF DEFENSE
WASHINGTON, THE DISTRICT OF COLUMBIA

19 JAN 1989

Honorable Sam Nunn
Chairman
Committee on Armed Services
United States Senate
Washington, DC 20510

Honorable Robert C. Byrd
Chairman
Committee on Appropriations
United States Senate
Washington, DC 20510

Honorable Les Aspin
Chairman
Committee on Armed Services
House of Representatives
Washington, DC 20515

Honorable Jamie L. Whitten
Chairman
Committee on Appropriations
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

This letter forwards the 1989 Report to Congress on the Strategic Defense Initiative, as required by Section 231 of the FY 1988/1989 Department of Defense Authorization Act.

This report serves as a summary of the SDI legacy of President Reagan, who launched the initiative with his historic speech of March 23, 1983. In addition, General James Abrahamson, the first Director of the Strategic Defense Initiative Organization, will retire at the end of January. This report also serves as a summary of where his able leadership has brought the program.

This report describes in detail our current assessment of the best program for the resolution of remaining technical issues, the validation of technologies, and the demonstration of our ability to integrate them. This program of research, development and testing would, if adequately funded, support a fully informed decision by the President and Congress in the future on whether to deploy a strategic defense of the United States. Such defenses could enhance deterrence and increase stability.

The SDI program is vital to U.S. and Allied security. As the President has directed, we are moving to provide the U.S. and its Allies with options to deploy a viable and highly effective nation-wide defense against ballistic missiles and options to deploy such defenses against theater ballistic missiles. In the nearer term, we are conducting an analysis to determine whether any earlier options exist to provide a more limited degree of protection to the United States. The program also provides a hedge against possible Soviet breakthroughs in defense research, and possible Soviet breakout from the ABM Treaty.

In 1987, the Joint Chiefs of Staff confirmed the long-term goal for SDI research. They also developed the performance requirements for the first major strategic defense deployment step that would provide a militarily useful contribution to deterrence. The performance standard for the first phase of a Strategic Defense System is based on the reality that ballistic missile defenses, acting in concert with our offensive forces, can significantly enhance deterrence. This does not mean that a first phase system would defend only military targets; it does mean that the layered defense concept that is fundamental to SDI would provide much greater assurance that we can prevent a nuclear war from ever occurring.

In Geneva, we have for three and a half years been discussing with the Soviets our desire to move to a more defense-reliant world. In January 1988, the U.S. tabled a draft Defense and Space Treaty that would provide a stable, predictable basis for developing and testing advanced defenses against strategic ballistic missiles, and for the deployment of such defenses if they prove feasible. We hope that we and the Soviet Union could move jointly to a more defense-reliant deterrence. However, we will not give the Soviets a veto over the U.S. ability to meet our strategic goals.

The technical progress of the SDI program has been excellent. A large majority of the contracts and experiments are on or ahead of schedule, and the record of testing successes has been outstanding. These accomplishments are a tribute to effective program management and the creative, dedicated efforts of thousands of people involved in the research effort across this Nation and among our Allies. In part because of this progress, poll after poll continues to indicate that the American people are solidly behind the President's vision of acquiring an effective means of countering a ballistic missile attack. Unfortunately, in the past five years, SDI has been the subject of unwarranted criticism, misunderstanding of the program, and budgets dramatically reduced from the President's requests. These have served to draw attention away from the objectives and progress of the program. Still, most responsible analysts now endorse at a minimum a robust research effort. Although Congress has repeatedly not provided the full budget requested by the Administration for SDI, it has steadily increased resources. This reflects a significant measure of bi-partisan consensus on the research aspects of the program.

The SDI program has unquestionably been hurt by the funding cuts from requested levels that have occurred. The development of defenses and the date at which possible deployment of defenses could occur have been delayed a number of times and technical risk has been increased. The program would be hurt even more by any further cuts. Because of these reductions and other factors, we have taken steps to restructure SDI. We seek maximum benefit from each dollar we spend; we also intend to fight for increased funding which is essential to the future viability of the program.

In an effort to reduce the overall costs of a first-phase Strategic Defense System, the Defense Department recently completed an intensive review of the modifications made to date toward this end. That review produced good news: the projected cost of the first phase of a Strategic Defense System has been reduced dramatically -- from the earlier estimate of $115 billion to $69 billion -- while maintaining the capability to contribute to deterrence. These cost reductions are explained in detail in chapter four of the Report.

The review also confirmed that SDI is proceeding in the right direction toward development of a comprehensive space- and ground-based Strategic Defense System.

The modified Phase I program brings costs down significantly while meeting important guidelines: continuing to emphasize research on space defense; providing for early deployment of space-based sensor systems -- which are vital to our strategic offensive forces as well as strategic defenses; maintaining the option to develop and deploy a limited protection system, given a national decision and the funding to do so; and maintaining a balance between near- and longer-term weapons technology programs.

Furthermore, the operational requirements developed by the Joint Chiefs of Staff for the initial phase of a Strategic Defense System have not changed, nor has the projected ability of the system concept to meet those requirements. This modified architecture, like the earlier one, takes into account likely Soviet countermeasures and U.S. survivablity measures. The two-tiered concept, with both space-based and ground-based interceptors, has not changed. What has changed is the distribution of functions within the modified architecture, as well as the application of technology.

I urge the Congress to support the President's FY1990 budget request for SDI.

Sincerely,

Frank C. Carlucci

1989 Report to the Congress on the

Strategic
Defense
Initiative

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Prepared by the Strategic Defense Initiative Organization

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A Personal Preface

This Report to the Congress on the Strategic Defense Initiative is my last as Director. For 5 years, it has been my great pleasure to work with Members of Congress and their staffs as we pursued the national goals first announced by President Reagan in March 1983. I thank each of you, both advocates and critics. I thank you all for your tough questions, for your thoroughness, for your open-mindedness, and for your commitment to national security. Your support has made possible the extraordinary progress we have made.

President Reagan's vision of a more secure world through defenses against ballistic missiles has sometimes been misunderstood—but I believe it represents an inspired mix of revised strategy, technical achievement and negotiated arms reductions. I am proud that SDI has made highly significant progress in all three areas. Many Americans have a new understanding of the role of defenses in deterring war and in protection against ballistic missiles, should deterrence fail. Second, SDI played a vital role in negotiations which brought reductions in nuclear weapons for the first time in history.with the potential of further cuts in the offing. Third, this report outlines the extraordinary technological progress we've made through SDI research.

Chapter 4 summarizes the technical progress achieved in the SDI research program—pointing out major advances in small, lightweight and affordable components for defensive interceptors; sensor developments for satellites and ground-based systems; and exciting progress in lasers and particle beam research. Chapter 4 also outlines the maturation of SDI's technology base programs and overall system concepts. Chapters 5 and 6 present the details of current and planned projects, while Chapters 7 and 8 summarize program management and funding plans. Appendices outline potential Soviet responses to SDI, allied research efforts, other security missions for SDI technology, and the SDI Technology Applications Program.

Technical progress, however, is not an end in itself. New SDI technology has strategic value principally as it contributes to the ability of the President and the Congress to make an informed decision on the technical feasibility and cost of developing and deploying ballistic missile defenses. To this end, I am pleased to report that our research has not only preserved but enhanced both near- and long-term options for ballistic missile defense. I am convinced such options will be shown to be survivable, militarily effective, and affordable—even in the face of expanding Soviet threats. Concepts to provide ballistic missile defense for our allies are also under investigation with their full participation.

Let me be more specific about the defensive options the SDI Program is in the process of creating. Given a national consensus to develop and deploy Phase I of a system that meets the initial military requirement established by the Joint Chiefs of Staff, the Defense Acquisition Board has found that a system can be researched, developed, acquired, and deployed for approximately $69 billion. This is a substantial cost reduction from earlier estimates, yet the system would still confront the Soviets with both space- and ground-based layers of defense. New and simplified alternatives, like "Brilliant Pebbles," should soon be validated. There are several variations of these simplified alternatives that have the potential for reducing costs dramatically lower than our current projection. Finally, for the long term, our research points to options that could employ combinations of advanced directed energy concepts and kinetic energy interceptors to create the longer term, very comprehensive and highly effective defense against Soviet attack.

Throughout the years that I have worn the Air Force uniform, it has been my privilege to serve our nation in many challenging ways and in many rewarding assignments. None, however, has been so rewarding as the one I am about to conclude. It has been a genuine privilege to work with the outstanding people in the Executive branch and the Congress on this historical undertaking that is so vital to our national security. My greatest satisfaction comes from the close association with the thousands of dedicated men and women in the Strategic Defense Initiative Organization; the Services and other agencies who manage our projects; and the laboratories, contractors, and universities...whose unflinching support, determination, and creativity made possible the tremendous progress we have enjoyed. I thank President Reagan, Secretary of Defense Carlucci, Former Secretary of Defense Weinberger, and the many people in industry and the government—both supporters and critics—who have allowed me to serve in this worthwhile endeavor.

James A. Abrahamson

James A. Abrahamson
Lieutenant General, USAF

Chapter 1

SDI Program in Perspective

STRATEGIC DEFENSE INITIATIVE
DEPARTMENT OF DEFENSE

Chapter 1

SDI Program in Perspective

This chapter describes the national security environment of the Strategic Defense Initiative (SDI), United States national security strategy, the challenge to United States security, and the response to that challenge. It also addresses overall SDI Program goals and decision criteria.

1.1 The National Security Environment of the SDI

The basic objectives of the SDI are best explained and understood in terms of the national security environment the United States and its allies face for the balance of this century and into the next. The United States and its allies face a number of challenges that threaten our security. Each of these challenges imposes demands and presents opportunities. Preserving peace and freedom is, and always will be, this country's fundamental goal. The essential purpose of United States military forces is to deter aggression, threats of aggression, and coercion against the United States and its allies. The deterrence provided by United States and allied military forces in the past has permitted the American people and their allies to enjoy peace and freedom.

For the past quarter century, assumptions of how nuclear deterrence can best be assured have been based on the concept that if the United States and the U.S.S.R. both maintain the ability to retaliate against nuclear attack, and if the United States could impose on the Soviet Union costs that are clearly out of balance with any potential gains, these abilities and threat would suffice to prevent nuclear war, or conflicts that could lead to nuclear war. The emphasis placed on particular Soviet assets that must be held at risk by United States forces to deter aggression has changed over time. Nevertheless, the strategy of relying on the threat of retaliation, provided by offensive nuclear forces as the primary means of deterring aggression, has not changed. This assumption served as the foundation for the United States approach to the Strategic Arms Limitation Talks (SALT). At the time the process began in 1969, the United States concluded that deterrence based on mutual vulnerability was not only sensible but necessary. The United States believed that both sides were far from being able to develop the technology for defensive systems that could enhance deterrence. However, since 1972 the Soviet Union has failed to show the necessary restraint, in both strategic offensive and defensive forces, that was an essential assumption of the United States strategic concept when the SALT process began. In addition, technologies that are applicable to ballistic missile defense have made such dramatic advances since 1972 that it may no longer be necessary to base deterrence solely on mutual vulnerability in the future.

The United States response to the strategic threat has, out of necessity, undergone a period of evolution during the past four decades that has adapted to the changing nature of the threat itself. The current strategic environment is characterized by:

- Quantitative and qualitative improvements in Soviet strategic offensive and defensive forces
- A long-standing and intensive Soviet research program in many of the same basic technological areas that the SDI Program addresses
- A continuing pattern of Soviet noncompliance with existing arms control agreements, including a significant violation of a central provision of the Anti-Ballistic Missile (ABM) Treaty.

1.2 National Security Strategy and Missions

The national security strategy of the United States seeks to enhance fundamental national interests. Specific United States national security objectives that reflect these interests provide the framework within which we determine the specific missions to be assigned to our military forces and hence the size, characteristics, and composition of forces the United States needs. A strategic defense must contribute, in combination with other United States forces and in concert with our allies, to the ability of the United States to carry out its national security strategy and thereby sustain our national interests. Military strategic defense missions that are able to contribute most directly to the national security objectives are listed in Figure 1-1. Further detail of these missions that an initial defense against ballistic missiles could accomplish is shown in Figure 1-2.

Deterrence requires that Soviet leaders believe they could not achieve any meaningful gain through resort to war and that the risks clearly outweigh any possible benefits. The Soviets must not only be denied confidence that an initial attack might succeed in its objectives, but they must know that even after such an attack, the United States would still possess a credible capability to continue to deny Soviet war aims. United States capabilities to limit damage to the nation, our forces, and our allies and effectively to deny Soviet war aims are thus essential contributors to deterrence.

1.3 Challenge to United States Security

The Soviet Union remains the principal threat to United States security and that of our allies. As part of its wide-ranging effort to further increase its military capabilities, the Soviet Union has improved its ballistic missile force, increasingly threatening the survivability of United States and allied deterrent forces and the leadership structure that commands them. Soviet forces equally threaten many critical fixed installations in the United States and in allied nations that support the nuclear retaliatory and conventional forces which provide the collective ability to deter conflict and aggression.

Figure 1-1
Strategic Defense Missions Derived From National Security Interests

National Interest

- U.S. survival, freedom, values
- Growth of freedom, democracy throughout the world
- Stable, secure world
- Strong alliances

National Security Objectives

- Deter or defeat attack and deter coercion
- Reduce reliance on nuclear weapons
- Preserve alliance strength
- Ensure space and ocean access
- Counter terrorism and security threats short of armed conflict

Strategic Defense Missions

- Enhance deterrence
- Limit damage
- Deny Soviet war aims

Offensive Challenge

Since 1969, when the SALT I negotiations began, the Soviet Union has built five new types of intercontinental ballistic missiles (ICBMs) and upgraded them nine times. The Soviet Union has also built seven new classes of ballistic missile submarines and five new types of submarine-launched ballistic missiles (SLBMs) and upgraded them three times. As a result, their missiles are much more powerful and accurate than they were several years ago. The alarming growth in the capability of Soviet ballistic missiles and in the number of ballistic missile warheads over the last decade gives the Soviets a prompt hard-target force capable of rapidly and significantly degrading our land-based retaliatory capability. In contrast, the United States has fielded only one ICBM since 1969—the Peacekeeper—and only in limited numbers. Since 1969, the United States has deployed only one new class of ballistic missile submarine and two new types of SLBMs. The resulting asymmetry between Soviet and United States forces has led to a destabilizing situation, one that must be redressed.

Figure 1-2
Fundamental Missions of a Strategic Defense

Enhance Deterrence

- Deny Soviet confidence in ability to plan or execute a successful attack
- Influence Soviet correlation of forces

Limit Damage to the U.S., Its Forces, and Its Allies (Including Through Theater Defense)

- Protect U.S. assets from Soviet attack
- Preserve U.S. ability to sustain and support its allies
- Defeat limited or unauthorized attacks

Deny Soviet War Aims

- Deny "maintain continuity of CPSU control"
- Deny "defeat and occupy NATO"
- Deny "neutralize the United States"
- Deny "dominate the postwar world"

Defensive Challenge

At the same time that it has worked to improve its offenses, the Soviet Union has continued to seek strategic advantage through the development, improvement, and expansion of both active and passive defense capabilities. These defenses provide the Soviet Union with a steadily increasing capability to counter the effectiveness of the retaliatory forces of the United States and its allies, especially if those forces were to be degraded by a Soviet first strike. These defenses also offer the Soviet Union increasing protection for assets that it values highly. Furthermore, current patterns of Soviet research and development on advanced defenses indicate that these trends will continue in the foreseeable future. If unanswered, continued Soviet defensive improvements will further erode the effectiveness of the existing United States strategic deterrent which is based almost exclusively on the threat of retaliation by offensive nuclear forces. Therefore, the challenge posed by the long-standing Soviet program of defensive improvements must be addressed.

Active Defenses

Today, Soviet active defenses are extensive. The Soviets have the world's largest air defense network, which they continue to improve, and the world's only operational antisatellite (ASAT) capability. The Soviet Union also is improving all elements of the world's only ABM system which is deployed around Moscow. In addition, the Soviets are developing and testing new ABM components that could allow construction of individual ABM sites in a matter of months rather than the years required for older ABM components. The Soviet Union also has an extensive and expanding network of ballistic missile detection and tracking radars.

Passive Defenses

The U.S.S.R. spends significant resources on passive defensive measures aimed at improving the survivability of its forces, military command structure, and national leadership. These efforts range from providing mobility for its latest generation of ICBMs to extensive hardening of various critical military and civil defense installations. Passive measures, together with active defenses, furnish the Soviet Union an area of relative advantage in deployed defensive capability and near-term defensive deployment options.

Treaty Noncompliance

Finally, the United States is very seriously concerned about Soviet noncompliance with arms control agreements, including the ABM Treaty. The Soviet large phased-array radar (LPAR) under construction near Krasnoyarsk in central Siberia has significant consequences. When considered as a part of a Soviet network of new radars, the Krasnoyarsk radar has the inherent potential to contribute to ABM radar coverage of a significant portion of the central U.S.S.R. The ABM Treaty, recognizing the contribution these radars could make, restricts deployment of early warning LPARs to the periphery of the national territory and oriented outward as one of the primary mechanisms for ensuring the effectiveness of the Treaty. Due to its location, orientation, and capability, the Krasnoyarsk radar is a significant violation of a central element of the ABM Treaty.

Against the backdrop of the Soviet pattern of noncompliance with existing arms control agreements, the Soviet Union is taking other actions which affect the United States ability to verify Soviet compliance. Some Soviet actions, like the extensive use of data denial measures during missile testing, will degrade the United States ability to monitor treaty compliance. Other Soviet actions contribute to the problems associated with monitoring Soviet compliance. For example, increasing quantities of Soviet mobile land-based strategic ballistic missiles will make monitoring and verification far more difficult.

1.4 Response to the Challenge

In response to the long-term pattern of Soviet offensive and defensive expansion, the United States is compelled to take complementary actions designed both to maintain security and stability in the near term and to ensure these conditions in the future. The United States is acting in three main areas.

Offensive Forces Response

First, in the near term, offensive nuclear retaliatory forces must be modernized. This is necessary to reestablish and maintain the offensive balance in the near term and to create the strategic conditions that will permit the United States to pursue parallel actions in the areas of arms reduction negotiations and defensive research. In 1981, the United States embarked on a strategic modernization program aimed at reversing a long period of relative neglect. This modernization program was specifically designed to preserve stable deterrence and, at the same time, to provide the incentives necessary to cause the Soviet Union to join the United States in negotiating significant reductions in the nuclear arsenals of both sides.

In addition to the United States strategic modernization program, the United Kingdom and France have important programs under way to improve their strategic nuclear retaliatory forces. The SDI Program does not negate the need for these United States and allied programs. Rather, the SDI Program depends on collective and national modernization efforts to maintain deterrence today as options are explored for possible future decisions on how the United States might enhance security and stability over the longer term.

Defensive Response

Second, steps must be taken to provide options for ensuring deterrence and stability over the long term, allowing the United States to counter the destabilizing growth of Soviet offensive forces and to channel long-standing Soviet propensities for defenses toward more stabilizing and mutually beneficial ends. In the near term, the SDI Program also responds directly to the ongoing and extensive Soviet ABM effort, including the existing Soviet deployments permitted under the ABM Treaty. The SDI research provides a necessary and powerful deterrent to any near-term Soviet decision to expand rapidly its ABM capability beyond that permitted by the ABM Treaty. This, in itself, is a critical task. Moreover, and of overriding significance in the longer term, the SDI Program offers the possibility of countering and reversing the dangerous Soviet offensive military buildup by moving to a better, more stable basis for deterrence and by providing new and compelling incentives to the Soviet Union to negotiate seriously reductions in existing offensive nuclear arsenals and to shift emphasis to defensive measures.

In our investigation of the potential of advanced defensive systems, the United States seeks neither superiority nor unilateral advantage. Rather, if the promise of SDI technologies is proven, the destabilizing characteristics of the current strategic environment could be rectified. And, in the process, deterrence would be strengthened significantly and placed on a foundation made more stable by reducing the role of ballistic missile weapons and placing greater reliance on defenses. If the SDI Program demonstrates that future defenses are feasible, we will consult with Congress and United States allies about next steps.

Arms Control Response

Third, the United States must continue its strong commitment to arms control. The United States would like, if effective defenses against ballistic missiles prove feasible, to alter the strategic relationship with the Soviet Union to a relationship based on greater reliance on defenses and less reliance on retaliation as the means to secure nuclear peace. While the United States must be prepared to proceed unilaterally along this course, we prefer that a transition to greater defense reliance proceed on a cooperative basis with the Soviet Union. We also seek greater understanding on both sides of the other's strategic defense activities. Such cooperation and openness could help enhance stability during the transition.

The United States' proposals in the Nuclear and Space Talks, taken as a whole, offer a means for a cooperative transition to greater reliance on defenses. We insist, however, that the Soviet Union correct its violation of the ABM Treaty involving the Krasnoyarsk radar in a verifiable manner before we will conclude any further strategic arms control agreements with the Soviet Union. The United States proposals include the following key characteristics:

- Offensive reductions. The United States seeks deep reductions in strategic offensive arms in a Strategic Arms Reductions Talks (START) agreement, with priority on reducing the most destabilizing systems. Such reductions would increase uncertainty for any potential attacker and would substantially decrease the demands put on a deployed strategic defense system.
- Technical development under the ABM Treaty. The United States wishes to retain the ABM Treaty unless and until a decision is made to move beyond it, while conducting research, testing, and development as required, which are permitted by the ABM Treaty. Of course, we also retain our existing right under the Treaty to develop and test certain ABM systems regardless of basing mode.
- Rights under the ABM Treaty. The United States is prepared not to withdraw from the ABM Treaty for a specific period of time for the purpose of deploying or acquiring capabilities for strategic defense. The United States insists that the sides retain withdrawal rights, recognized in international law, such as those that could be exercised in the event that a side's supreme interests are jeopardized, as well as termination and suspension rights in the event the treaty is materially breached.
- Space-based sensors. The United States has proposed that the sides agree not to object, on the basis of the ABM Treaty, to the development, testing, or deployment of each other's space-based sensors. Acceptance of this proposal would build confidence by facilitating the development of stabilizing space-based sensors. It could also avert potentially unsolvable verification problems and the future disputes they could engender.

- Space testing. In order to demonstrate that testing of space-based components capable of substituting for ABM interceptor missiles, which is permitted by the ABM Treaty, does not represent the deployment of such components, the United States is prepared to carry out such permitted testing only from designated ABM test satellites. The United States view is that the number of designated ABM test satellites in orbit simultaneously shall not exceed a number well short of that associated with any realistic deployed capability. The United States believes the number 15 falls well below that threshold. The United States has also proposed notification procedures for ABM test satellites.
- Freedom to deploy defenses. The United States could accept a limited period of nonwithdrawal from the ABM Treaty if, after the end of this period and following intensive discussions with the Soviet Union concerning strategic stability and 6 months notification, there is a right to deploy defenses beyond those allowed by the ABM Treaty, without further reference to that Treaty.
- Increased predictability. The United States has proposed a set of confidence-building measures to provide predictability regarding the future nature, scope, and pace of the strategic defense programs of both sides. This increased transparency would lessen uncertainty in the United States-Soviet strategic relationship.

In summary, the United States position in the Nuclear and Space Talks offers an approach to a cooperative United States-Soviet transition to greater reliance on strategic defenses and to reducing substantially strategic offensive arms. Thus, arms control, although not an end in itself, can complement our other ongoing efforts to maintain security and stability.

1.5 Program Goal and Objectives

From its beginning, the SDI Program has had the same overall goal—to conduct a vigorous research and technology program that could provide the basis for an informed decision regarding the feasibility of eliminating the threat posed by ballistic missiles of all ranges and increasing the contribution of antiballistic missile defense systems to United States and allied security. Within this goal, the SDI Program is preserving options for near-term deployment of limited ballistic missile defenses.

Moreover, the Program is carried out in full consultation with and, where appropriate, with participation of our allies. The SDI Program includes research on theater missile defense. Forward-deployed United States forces and our allies must be capable of responding to a substantial ballistic missile threat from the Warsaw Pact nations and other countries developing a ballistic missile capability. While the Intermediate-Range Nuclear Forces (INF) Treaty provides for the removal and destruction of intermediate-range ground-launched cruise and ballistic missiles from the inventories of both the United States and the Soviet Union, short-range ballistic missiles (SRBMs) remain in the Soviet inventory. Active theater missile defenses will deter the use of those systems and provide an insurance policy against cheating by the Soviets. Furthermore, because the INF Treaty is limited to the United States and U.S.S.R., intermediate-range ballistic missiles (IRBMs) are not eliminated for other nations. Additionally, it is expected that retargeted Soviet ICBMs and SLBMs will be used to hold critical theater assets at risk. Thus, although the balance of the threat has changed somewhat, the full threat range remains to be countered and the fundamental threat requirements for theater missile defense remain unchanged.

The SDI Program is being conducted in compliance with all existing treaty obligations. Program emphasis is on non-nuclear technologies.

1.6 Program Decision Criteria

An effective strategic defense system that will counter offensive ballistic missiles to a meaningful degree will have to meet three specific criteria. These criteria have guided the Program from the beginning.

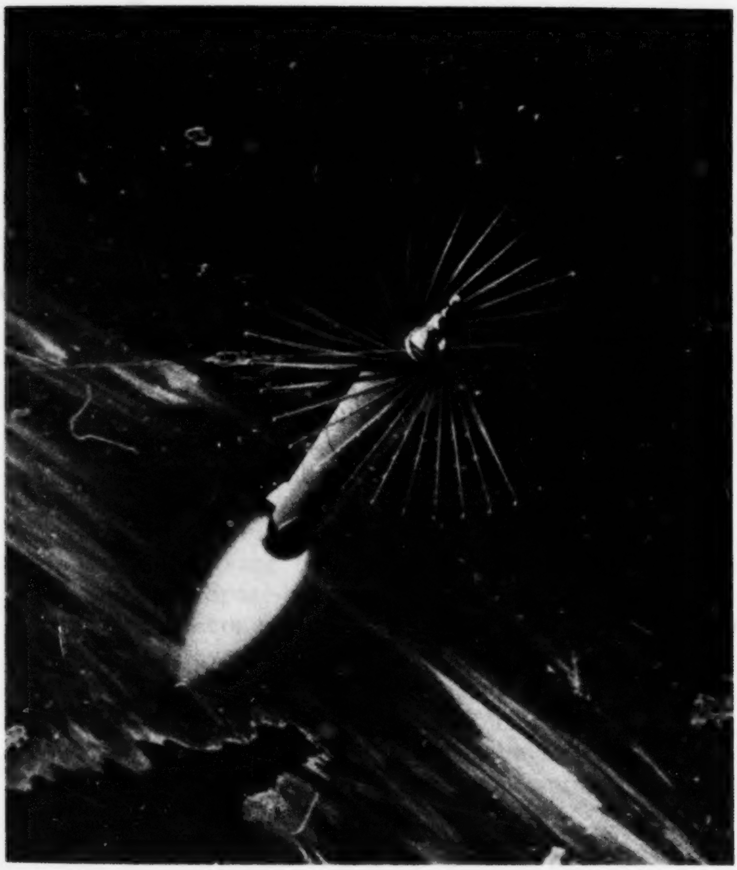
The first criterion is military effectiveness. A defense against ballistic missiles must be able to destroy a sufficient portion of an aggressor's attacking force to deny him confidence that he can achieve his objectives. In so doing, the defense should have the potential to deny that aggressor the ability to destroy a militarily significant portion of the target base he wishes to attack.

The second criterion is adequate survivability. Defenses must maintain a sufficient degree of effectiveness to fulfill their mission, even in the face of determined attacks on the defenses and, perhaps, loss of some individual components. Such a capability will maintain stability by discouraging such attacks. Survivability means that the elements of the defensive system must not be an appealing target for defense suppression attacks. The offense must be forced to pay a penalty if it attempts to negate the defense. This penalty should be sufficiently high in cost and/or uncertainty in achieving the required outcome that such an attack would not be contemplated seriously. Additionally, the defense system must not have an "Achilles' heel." In the context of the SDI, survivability would be provided not only by specific technical "fixes" such as employing maneuver, sensor protection, and protective shielding materials, but also by using such strategy and tactical measures as deception, redundancy, and self-defense. System survivability does not mean that every element of the system need survive under all sets of circumstances; rather, the defensive force as a whole must be able to achieve its mission, despite any degradation in the capability of some of its components.

The third criterion is that the defensive options generated discourage an adversary from overwhelming them with additional offensive capability. The SDIO seeks defensive options—as with other military systems—that are able to maintain their defense capabilities more easily than countermeasures could be taken to try to defeat them. This criterion is couched in terms of cost effectiveness at the margin; however, it is much more than an economic concept.

Chapter 2

Strategic Defense System Concept



The SDI Program is providing new concepts and innovative technology options, such as the artist rendering of the interceptor shown here, that could be achieved at far less than the costs estimated only a few years ago.

Chapter 2

Strategic Defense System Concept

The SDI Program is providing new concepts and innovative technology options for near- and long-term defensive capabilities that could be achieved at far less than the costs estimated only a few years ago. This chapter summarizes key strategic defense concepts and analyses; expected threats; system operational requirements; and initial, follow-on, and theater architectures.

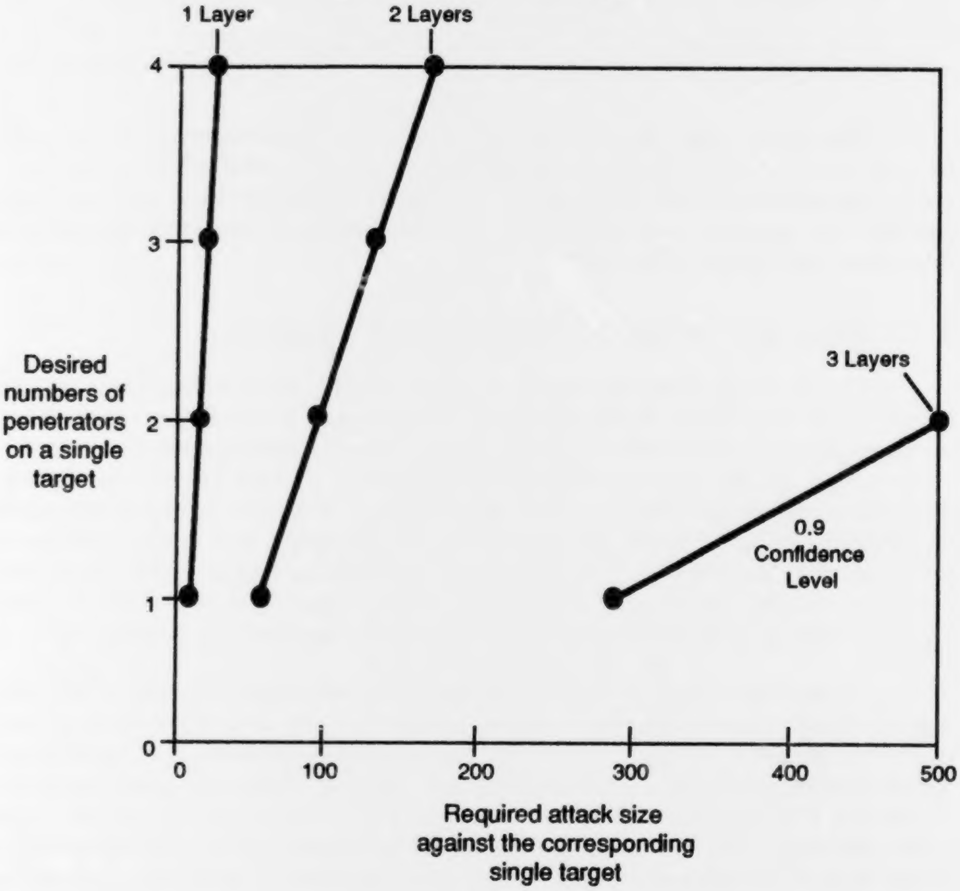
2.1 Strategic Defense Concepts and Analysis

The most significant differences between the Safeguard ballistic missile defense system the United States deployed in the mid 1970s and a system born from SDI will be the presence of non-nuclear technologies and boost/post-boost defense capabilities. This in-depth defense strategy relies first on the ability to react immediately following detection of the lift-off (or boost) of a ballistic missile, continues as that missile deploys its payload of nuclear warheads (in the post-boost layer), and finally protects U.S. targets as those weapons reach the midcourse and terminal layers. This concept would constitute a highly effective and resilient system. This report will refer to the three layers of defense as boost and post-boost, midcourse, and terminal, respectively.

To understand how a multilayered approach contributes to system effectiveness, it is worthwhile to explore an example. Figure 2-1 shows a three-layered system where each layer, working independently, possesses an effectiveness of 80 percent and the attacker requires a 90 percent confidence of success. Conversely, each layer allows 20 percent of attacking weapons to "leak through." If a Soviet war planner is faced with a one-layer defense, he has to dedicate 20 weapons (reentry vehicles [RVs]) to a single target to ensure that two RVs have high probability of penetrating the defenses. Faced with two layers, that planner has to allocate approximately 100 RVs. Against three layers, a number as massive as 500 reentry vehicles must be allocated per target to ensure a high probability that two will penetrate.

Because of this leverage, the SDI Program provides options for a multilayered defense involving both space- and ground-basing of sensors and defensive interceptors. Space-based interceptors make an ideal first layer because they can strike against boosters and post-boost vehicles. Destroying a booster has the benefit of destroying several RVs for every intercept. If a booster is missed, there is still an opportunity to go after the post-boost vehicle. If a post-boost vehicle is intercepted, even after several RVs have been off-loaded, the remaining unlaunched warheads are destroyed. It is in this high payoff region of boost and post-boost interception that much of the SDI Program has been concentrated. The technology challenge derives

Figure 2-1
Attack Requirements for Layered Defenses
(20% Layer Leakage)



from the shortness of time in the boost and post-boost periods, each of which lasts from 3 to 5 minutes, and the survivability of space-based defense elements.

Ground-based interceptors come into play in the midcourse layer, which covers approximately 20 minutes. The technical challenge to midcourse defenses is the ability of space- and ground-based sensors to discriminate between reentry vehicles and large numbers of accompanying decoys. This is a second major area of emphasis in the research program.

The terminal period can last a minute and a half. As remaining warheads and decoys reenter the atmosphere, lighter decoys slow down and are therefore distinguishable, making the targeting of the warheads easier. Interceptor, surveillance, and command and control technologies for all layers constitute the third major area of research to ensure effective defense in the last layer.

2.2 Threat

Strategic defense system design is based on the need to counter a Soviet offensive threat even as it survives a defense suppression threat. The threat makeup is dynamic and evolutionary. As the threat changes, the defense system design and architecture must also evolve.

Given the evolutionary, dynamic nature of the threat and our uncertainty regarding specific Soviet capabilities and intent, a threat cannot be definitively specified. Changes in specific aspects of threat may result from Soviet technology advances or from political factors, such as arms reduction treaties. Theoretically possible offensive threat enhancements include proliferation of reentry vehicles, multiple post-boost vehicles per booster (parallel busing), faster-burn boosters, maneuverable RVs, penetration aids, etc. Evolutionary enhancements to the defense suppression threat may include both direct threats to defense system elements, such as greater numbers of co-orbital antisatellite (ASAT) weapons, improved direct-ascent ASATs, directed energy and kinetic energy weapons, space mines, etc., as well as weapon employment strategies to negate defense system operations and performance (e.g., nuclear precursor attacks). Changes in offensive threat stress system performance, while changes in defense suppression threat stress system survivability and durability. The SDI Program includes continuing research projects to understand how evolution of the threat can impact strategic defense system performance.

2.3 Joint Chiefs of Staff Operational Requirements

The Joint Chiefs of Staff (JCS) formally provided operational requirements for Phase I of a Strategic Defense System (SDS) in June 1987. The initial requirements acknowledge and confirm the President's long-term objective "to develop a thoroughly effective defense that will protect the United States and its allies from the threat of attack from ballistic missiles of all ranges" and also prescribe a minimum performance level which must be achieved in the first phase of deployment.

2.4 Initial Architectures

An initial multilayered strategic defense system architecture, using kinetic energy technologies, can be defined as one that meets the JCS operational requirements. To support this architecture, there must be an investment in interceptor development and in creation of an infrastructure of sensors and battle management capability. However, once this investment is made, performance can be largely determined by adjusting interceptor types and numbers.

Alternative architectural concepts also exist for a Limited Protection System (LPS) in the mid 1990s using technology under development for SDS Phase I and follow-on phase elements. An LPS could be developed and deployed given a national decision and the funding to do so. However, an LPS can provide only limited protection to a selected target area.

Relative increase in system effectiveness for increased investment has been the subject of parametric analyses. The analyses include consideration of the architecture example used earlier. The results indicate that (a) costs are essentially constant for research and development of the Phase I system, regardless of what may be deployed, and (b) costs are essentially constant for acquiring the Phase I system infrastructure (sensors and battle management) regardless of numbers of interceptors deployed.

The initial SDS Phase I architecture incorporates the elements listed in Table 2-1. (Details of SDS Phase I elements are provided in Chapter 5.) Inherent in this architecture is an infrastructure that will support functions of elements of the initial and of a future strategic defense system.

The two-layer SDS Phase I architecture is shown in Figure 2-2. This architecture employs both a space-based interceptor (SBI) and a ground-based interceptor (GBI), previously ERIS, to give the system a resiliency against Soviet countermeasures. Acquisition of more SBI or GBI will be determined by factors shown in Figure 2-3.

As the latter figure shows, the significant countermeasures to the SBI are a shortened timeline imposed by the target (booster or post-boost vehicle) and ASAT weapons. Likewise, if the Phase I system's ability to discriminate reentry vehicles from decoys is reduced by better penetration aids or sensor degradation, then the GBI becomes less effective. As these particular threats develop, the Phase I system performance could be restored by increasing the numbers of interceptors of one or both types with relatively minor changes in the sensor suite and battle management elements.

2.5 Follow-on Architectures

Follow-on architectures to the SDS Phase I architecture provide an evolutionary approach that can respond to the threat, i.e., branch and block approach. Near-term research in kinetic interceptor technology has potential to provide capability for the third layer, terminal defense, in a follow-on phase architecture. The leading contender is the High-Endoatmospheric Defense Interceptor (HEDI). Longer-term kinetic energy research will refine the technology for hypervelocity guns for this layer.

A significant part of the SDI Program is devoted to research on advanced concepts. Such concepts present a potential for upgrades to SDS Phase I and new capabilities for maintaining an effective strategic defense as Soviet capabilities evolve. In fact, the current intent is to demonstrate technical feasibility of the most promising advanced concepts before a commitment to full-scale development of Phase I is made. This phased development approach would take advantage of and build on the supporting infrastructure of surveillance and battle management capabilities in Phase I.

Table 2-1
Elements of Initial System

SYSTEM ELEMENTS	PRIMARY FUNCTIONS
Boost Surveillance and Tracking System (BSTS)	• Detection of missile launches • Acquisition and tracking of boosters • Booster kill assessment
Space-Based Surveillance and Tracking System (SSTS)	• Acquisition and tracking of post-boost vehicles and reentry vehicle clusters, ASATs, and satellites • Kill assessment
Ground-Based Surveillance and Tracking System (GSTS)	• Closely spaced object resolution • Tracking of reentry vehicles and penetration aids • Discrimination of reentry vehicles from penetration aids • Kill assessment
Ground-Based Radar (GBR)*	• Acquisition and tracking • Discrimination of reentry vehicles from penetration aids
Ground-Based (Exoatmospheric) Interceptor (GBI)	• Destruction of reentry vehicles in late midcourse
Space-Based Interceptor (SBI)	• Destruction of boosters, post-boost vehicles, and ASATs • Destruction of reentry vehicles in early midcourse
Command Center (CC)	• Human decisionmaking • Communications • Battle plan execution • Guidance for system operation and integration functions (SOIF)

* GBR is currently under consideration for inclusion in Phase I.

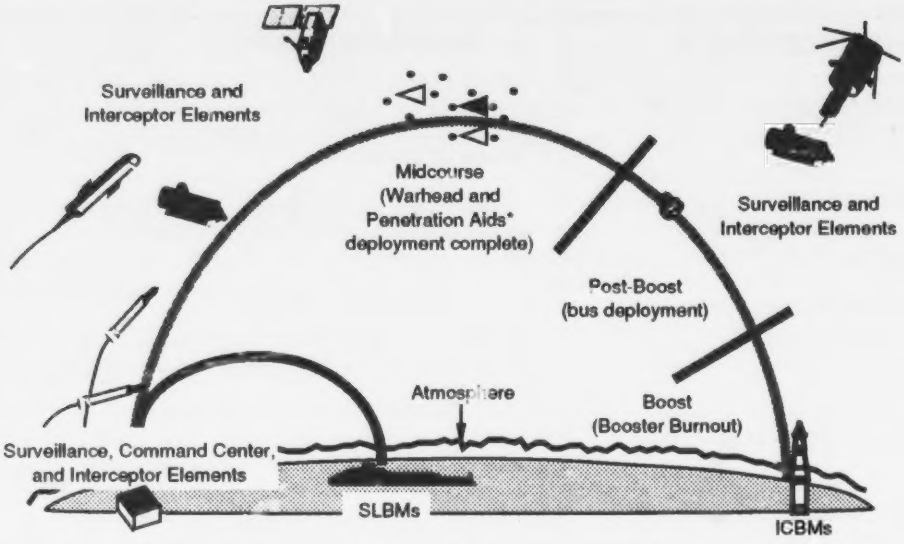
The two leading contenders for advanced systems are the laser and particle beam devices.

Laser research currently offers different options for the future. The ground-based element would use a free electron laser and relay mirrors to destroy boosters. A chemical laser is the preferred technology for the space-based element.

Neutral particle beams offer the potential to destroy not only boosters or post-boost vehicles, but also reentry vehicles. The element would have to be space based because the beam cannot penetrate the atmosphere.

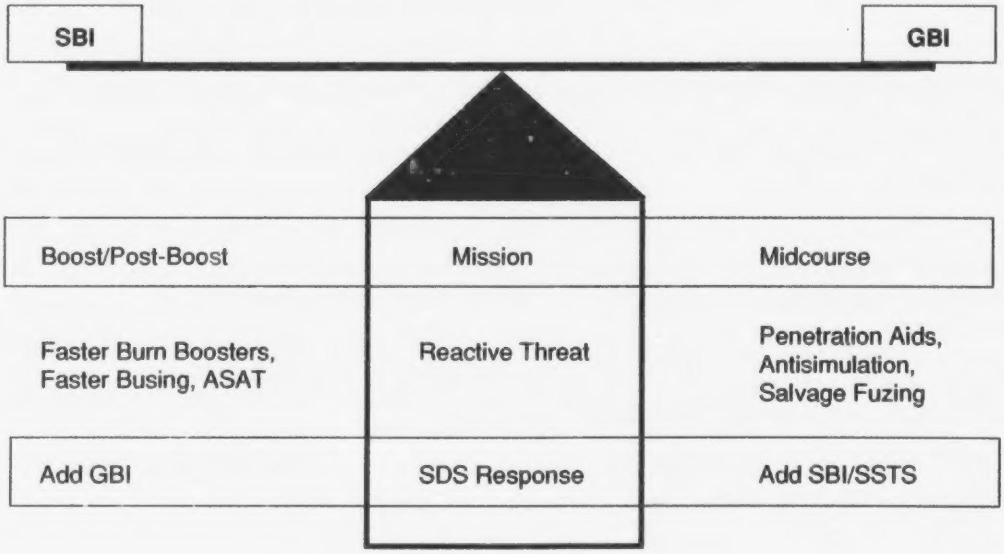
Other technologies are also being explored and are summarized in Table 2-2. Candidate follow-on elements are described in Chapters 5 and 6.

Figure 2-2
SDS Phase I Architecture


Surveillance and
Interceptor Elements
Midcourse
(Warhead and
Penetration Aids*
deployment complete)
Surveillance and
Interceptor Elements
Post-Boost
(bus deployment)
Atmosphere
Boost
(Booster Burnout)
Surveillance, Command Center,
and Interceptor Elements
SLBMs
ICBMs

* Penetration aids are devices, such as decoys, that are used to try to confuse defenses.

Figure 2-3
Phase I Interceptor Resiliency



Boost/Post-Boost	Mission	Midcourse
Faster Burn Boosters, Faster Busing, ASAT	Reactive Threat	Penetration Aids, Antisimulation, Salvage Fuzing
Add GBI	SDS Response	Add SBI/SSTS

Table 2-2
Follow-on Candidate Elements

SYSTEM ELEMENT	PRIMARY FUNCTIONS
High-Endoatmospheric Defense Interceptor (HEDI)	• Destruction of reentry vehicles after reentry
Space-Based Laser (SBL)	• Destruction of boosters, post-boost vehicles, and ASATs • Interactive discrimination
Ground-Based Laser (GBL)	• Destruction of boosters, post-boost vehicles, and ASATs • Interactive discrimination
Space-Based Neutral Particle Beam (NPB)	• Interactive discrimination • Destruction of boosters, post-boost vehicles, reentry vehicles, and ASATs
Ground-Based Hypervelocity Gun (HVG)	• Destruction of reentry vehicles in late terminal phase
Space-Based HVG	• Destruction of boosters, post-boost vehicles, and ASATs • Destruction of reentry vehicles in early midcourse

2.6 Theater Architectures

The theater defense program within SDI acknowledges that a strategic defense system could also provide protection to our allies. For example, an SS-19 aimed at Europe could be intercepted by the same space-based assets that would be employed if it were on a trajectory to the United States. Some special provisions have to be made for the short-range missile threat. This latter requirement is a focus of joint efforts with countries that have signed a Memorandum of Understanding on the SDI Program. These countries include the United Kingdom, the Federal Republic of Germany, Italy, Israel, and Japan.

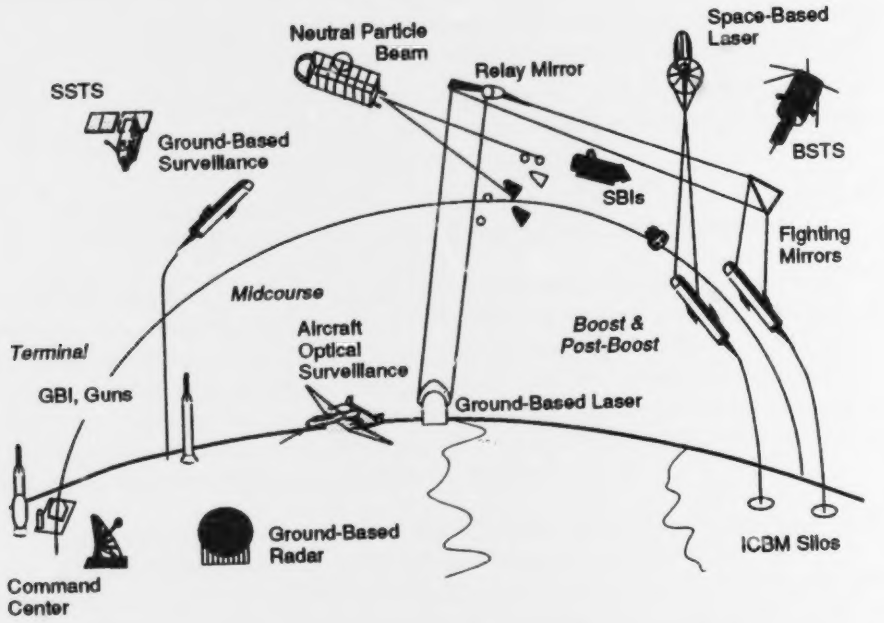
In March 1988, the JCS approved an operational concept for theater missile defense that encompasses four basic elements: passive defense; active defense; attack operation; and command, control, communications, and intelligence (C^3I). Complete theater missile defense requires a combination of each of these elements. SDI technology development will concentrate on the means to provide layered active defenses and related C^3I and to understand the contribution and requirement of passive defense and attack operations. The actual definition of the role of each element is a service and/or an ally responsibility.

2.7 Summary

The SDI Program is making rapid progress in providing the foundation for an informed decision on the development and acquisition of a multilayered strategic defense against ballistic missiles. SDI efforts in architecture, producibility, and better technology are also making dramatic progress in cost reduction to ensure that an effective SDS could also be affordable.

Chapter 3

SDI Program Strategy


Neutral Particle Beam
Space-Based Laser
SSTS
Relay Mirror
BSTS
Ground-Based Surveillance
SBIs
Fighting Mirrors
Midcourse
Terminal
Aircraft Optical Surveillance
Boost & Post-Boost
GBI, Guns
Ground-Based Laser
Ground-Based Radar
ICBM Silos
Command Center

The general SDI Program strategy is to maintain a balance between near-term and longer-term technologies such as those illustrated above.

Chapter 3

SDI Program Strategy

This chapter outlines the strategy being pursued under the SDI Program. The general strategy is to conduct an overall program that maintains a balance between near-term and longer-term technologies. The underlying theme is to support an evolutionary approach.

3.1 An Evolutionary Approach

The evolutionary development and deployment approach is premised on continually building from initial capability in response to evolving threats. This calls for incremental improvements in the following three essential functional capabilities:

- Sensing to enhance national capabilities for tactical warning and attack assessment and surveillance of satellites for space defense
- Command and control for operation of a strategic defense system and the communication networks necessary to integrate interceptors and, later, advanced devices with sensors
- Engagement by the defensive interceptors and advanced devices which are capable of destroying ballistic missile threats.

The notional schedule for this evolutionary approach is illustrated in Figure 3-1. The schedule shows that demonstration and validation of Phase I technologies and concept exploration of follow-on technologies are being pursued in parallel. It also shows that certain sensors as well as the command and control for Phase I are planned to enter full-scale development before the interceptors for that phase. Sensors are also needed to support missions other than strategic defense (such as early warning of ballistic missile attack and surveillance to support treaty monitoring).

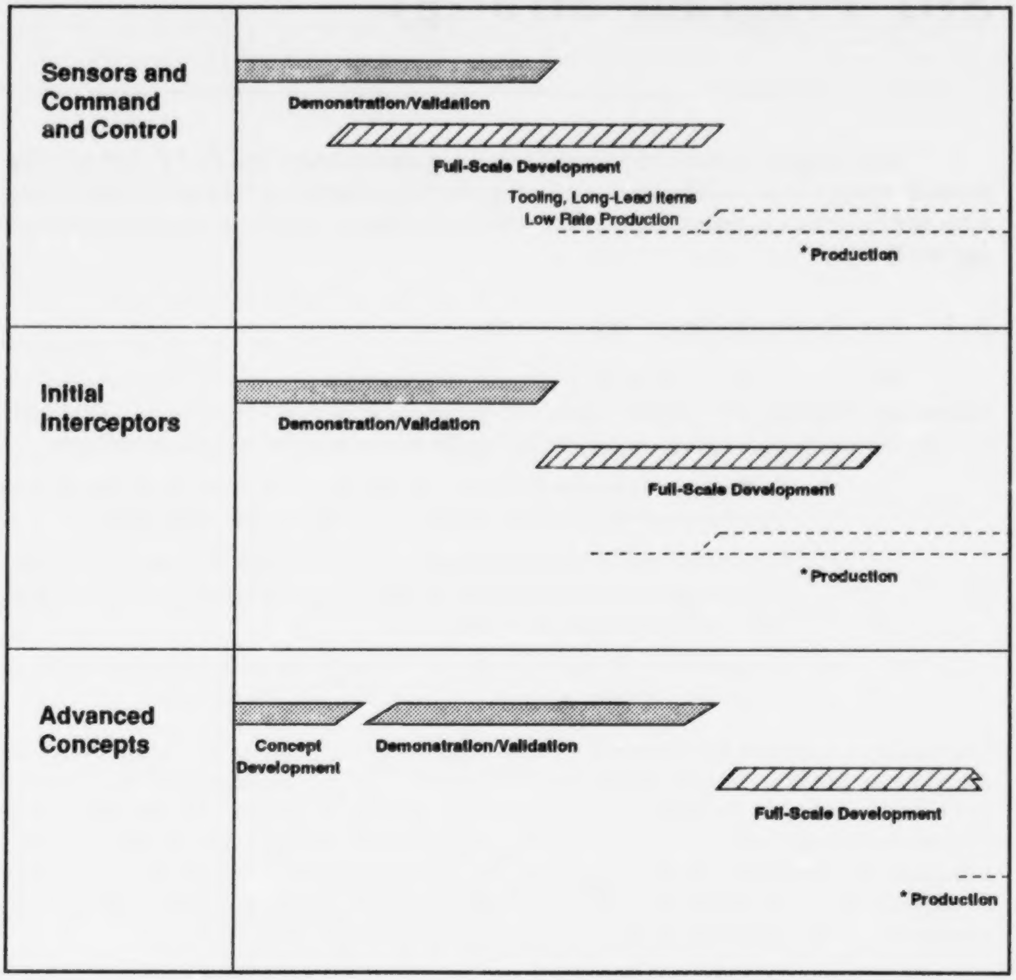
The planned program will allow the SDIO to pursue vigorously the definition of the system architecture that best satisfies mission requirements in the face of the threat and in recognition of available technology and resources. In this sense, the SDI Program strategy is to provide a number of development and deployment options until decisions are made to proceed into the next phase of system acquisition.

3.2 Program Structure

To implement the above strategy, the SDI Program has been structured into groups of projects that are contained within the following functional areas:

- Detect an attack and control, operate, and integrate the defense

Figure 3-1
Notional SDI Program Schedule



* If a decision is made to proceed with deployment

- Engage and destroy attacking objects with:
  - — Interceptors suited for initial defensive system concepts
  - — Advanced concepts suited for follow-on defensive systems
- Provide essential support to the defense
- Furnish the system analysis, engineering, and testing capabilities necessary for system development.

The following discussion explains how six program elements (PEs) in which SDIO receives funding relate to the above requirements. For FY 1990 and beyond, a seventh PE has been requested to provide for full-scale development of the BSTS.

The projects that support detection and control, operation, and integration are contained in two SDI PEs: surveillance, acquisition, tracking, and kill assessment (SATKA) and the battle management part of the systems analysis/battle management (SA/BM) program element. The SATKA program element provides the research and technology development efforts necessary to identify and validate various sensor concepts including (1) missile launch, or boost, detection sensors, (2) post-boost and midcourse surveillance and discrimination sensors, and (3) late midcourse and terminal surveillance and discrimination sensors. The battle management effort develops the technologies required to support a responsive, reliable, and survivable command center (CC) and associated system operation and integration functions (SOIF). (The new terminology CC/SOIF replaces the former battle management/command, control, and communications [BM/C^3] term.) The CC is an element of a strategic defensive system.

The projects that support engagement and destruction of attacking objects are contained in two other SDI Program elements: kinetic energy weapons (KEW) and directed energy weapons (DEW). The KEW program element is focused principally on the interception and destruction of ballistic missiles or their warheads (reentry vehicles [RVs]) through the use of hit-to-kill projectiles. Both space-based and ground-based kinetic energy concepts are being investigated. Some of the kinetic energy concepts are considered suitable as initial interceptors because of their technological maturity. Other kinetic energy concepts may later be used to augment the initial interceptors. The DEW program element provides the research and technology development required to identify and validate the most promising directed energy concepts including ground- and space-based lasers, space-based particle beams, and support for nuclear directed energy devices. These concepts are considered most suitable for follow-on defensive systems.

Projects that provide for research to support any defensive system are contained in the survivability, lethality, and key technologies (SLKT) program element. This program element develops key technologies, e.g., those that support power needs and launches into space, and those that relate to survivability, lethality, and countermeasures for a future defensive system.

Innovative science and technology (IST) and small business innovative research (SBIR) projects also create new and advanced, high-payoff technologies. These projects are funded from the SATKA; KEW; DEW; SA/BM; and SLKT program elements.

System analysis and engineering capabilities necessary for system development are contained in the analysis and engineering projects of the SA/BM program element. These projects provide program guidance and support activities for demonstration and validation of elements of Phase I and for follow-on system concepts. Research activity such as the National Test Bed as well as other experimental platforms (e.g., the Airborne Optical Adjunct [AOA] test bed in the SATKA program element) supports the integrated testing that is necessary for technology validation and system development.

Chapters 5 and 6 convey the details of the research and technology projects contained in the SDI Program. Figure 3-2 indicates the correlation of key activities and related projects with the budgetary program element categories.

Figure 3-2
Correlation of Major Program Activities With Budgetary Program Elements

ACTIVITY	KEY PROJECTS	PROGRAM ELEMENTS
Sensors and CC/SOIF	BSTS	SATKA
	Midcourse (SSTS, GSTS)	SATKA
	GBR	SATKA
	CC/SOIF	SA/BM
Initial Weapons and Other KE Concepts	SBI	KEW
	GBI	KEW
	HEDI	KEW
	HVG	KEW
	Theater Defense	KEW
Advanced Concepts	GBL	DEW
	SBL	DEW
	NPB	DEW
	NDEW	DEW
	ATP	DEW
Key Technologies	Survivability	SLKT
	Lethality and Target Hardening	SLKT
	Power and Power Conditioning	SLKT
	Space Transportation	SLKT
	Materials and Structures	SLKT
System Analysis and Engineering	Phase I System Engineering	SA/BM
	SDS Engineering and Support (producibility and logistics, advanced architectures)	SA/BM
	National Test Bed	SA/BM
Management	Program Management	All PEs
	SDIO HQ Management	Mgmt

3.3 Impact of Reduced Funding on Program Strategy

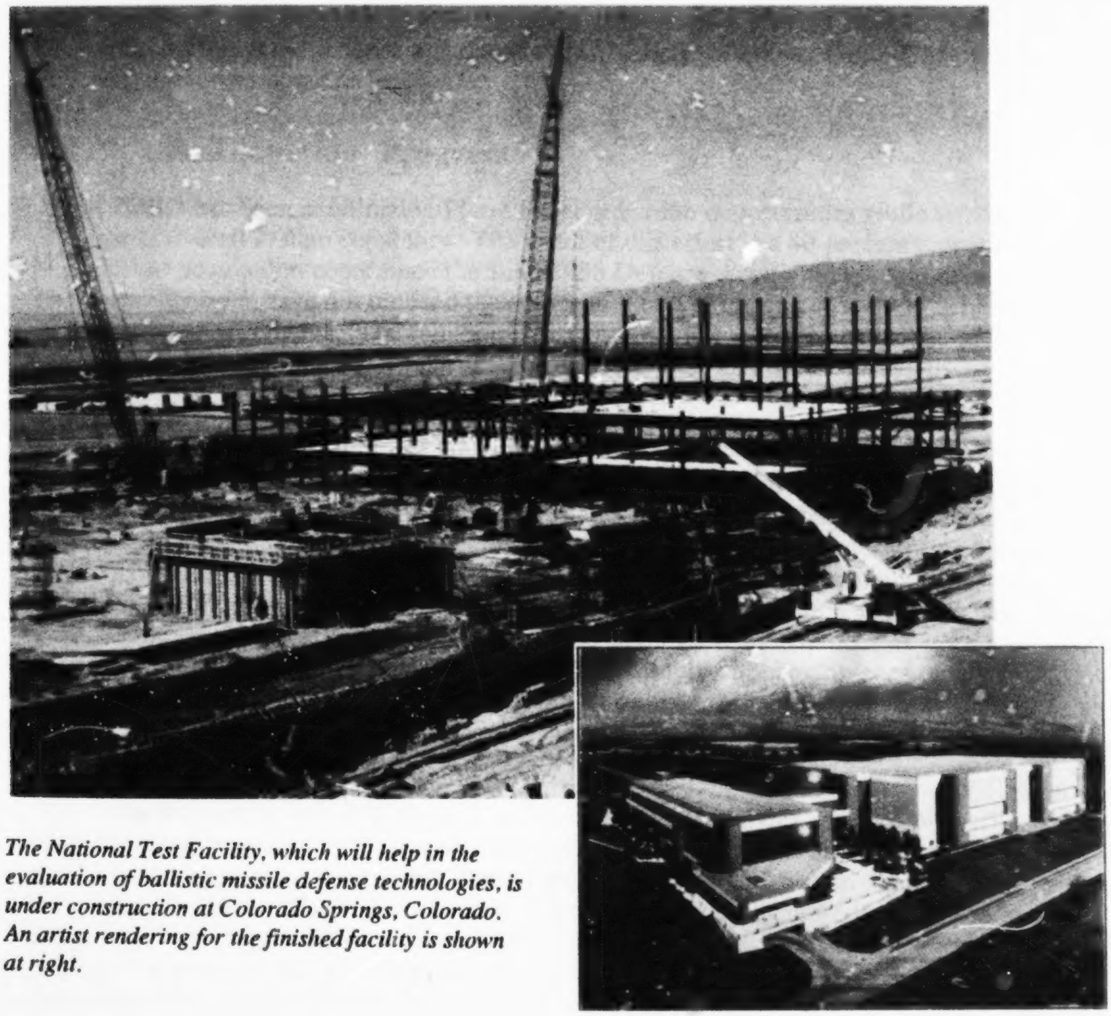
From FY 1985 through FY 1989, the SDI Program funding has been reduced to about 70 percent of the amount requested by the President in his earlier budget submissions. The funding requested was considered critical to establish a basis for an informed decision to develop and eventually deploy a strategic defense system in the early 1990s. As a result of these significant cuts, delays in major projects and deep reductions in technology base alternatives supporting major projects have occurred. At first, this led to a delay of several years in the date that was originally envisioned by the Fletcher Commission study for the development of a strategic defense system. Also, risks associated with successfully validating the technology increased after each cutback because fewer alternative paths were available.

Then, at the beginning of FY 1988, the FY 1989 DOD budget submission was reexamined and resulted in the submission of the smallest request since FY 1986. Subsequently, SDIO received budget guidance for FY 1989 through FY 1994. This guidance reduced by 26 percent the amount that was presented to the first Defense Acquisition Board Review in June 1987 as required to reach a decision to enter full-scale development for a Phase I system in the early 1990s. The cutback in funding affected all SDI-planned research and resulted in an SDI Program plan that adopted a revised program strategy. This strategy differs from that previously used in that all initial system technology will not be validated at the same time. Rather, technology for sensors and command and control functions will be validated first, then initial kinetic energy interceptors, and later advanced concepts, such as directed energy elements, for follow-on systems.

In summary, the overall impact of the funding cuts has been to lengthen the period over which decisions to develop and deploy an SDS can be made in order to preserve, with higher risk than originally planned, the technology options for initial and follow-on systems.

Chapter 4

Significant Progress in SDI



The National Test Facility, which will help in the evaluation of ballistic missile defense technologies, is under construction at Colorado Springs, Colorado. An artist rendering for the finished facility is shown at right.

Chapter 4

Significant Progress in SDI

Significant progress has been achieved this past year in defining strategic defense system concepts and, because of this, in the ability to refine cost estimates for acquiring a strategic defense system. One key indicator of this progress is that projected acquisition costs of an effective Phase I architecture have been reduced from $115 billion to $69 billion in FY 1988 dollars. In addition, major advances have occurred in technology base activities which provide the basis for possibly reducing the cost of upgrades to SDS Phase I and for new capabilities for follow-on phases. The result is a more realistic prospect than existed a year ago of achieving an effective and affordable multilayered defense against strategic ballistic missiles. Highlights of the SDI Program are summarized below.

4.1 Cost Reduction Progress

SDIO has been scrutinizing Phase I cost reduction opportunities while striving to maintain overall system capability. The result of this effort is a 40-percent reduction in projected acquisition costs since the June 1988 Defense Acquisition Board review. The cost reductions have not reduced the ability of the SDS Phase I concept to achieve JCS mission requirements. The remaining discussion will present an overview of the cost analysis techniques used, details of the cost reductions, and future cost goals.

4.1.1 Cost Analysis Techniques

Current Service methods and standard processes used for estimating costs for all military systems are used to develop estimates for the SDS Phase I architecture. Service cost analyses are based on actual cost histories of existing systems and on projections of the impacts of new technologies and processes. Minor changes in cost estimating methodologies were made only in the rare cases where new reference data were available. The cost reductions observed between June and October of 1988 are the result of finding a better way to do the job, not simply "improving" cost analysis procedures.

4.1.2 Cost Reductions

Reductions to the SDS Phase I architecture cost estimates resulted primarily from expected increased space-based interceptor performance and also from reduced sensor redundancy and streamlining of the command center and system operation and integration functions. These changes were possible because of increased confidence in technology development and because of the institution this past year of a system engineering process that increases emphasis on architecture efficiency. The specific cost reductions are shown in Table 4-1.

Table 4-1
Reduction in Phase I System Estimated Acquisition Costs
(In Billions of FY 1988 Dollars)

ELEMENT	JUNE 1988	OCTOBER 1988	$ REDUCTION	% CHANGE
Boost Surveillance and Tracking System (BSTS)	9.0	8.0	-1.0	-11%
Space-Based Surveillance and Tracking System (SSTS)	12.6	9.2	-3.4	-27%
Ground-Based Surveillance and Tracking System (GSTS)	3.6	3.3	-0.3	-8%
Space-Based Interceptor (SBI)	52.0	17.7	-34.3	-66%
Ground-Based Interceptor (GBI)	4.8	5.8	+1.0	+21%
Command Center/System Operation and Integration Functions (CC/SOIF)	14.6	7.3[1]	-7.3	-50%
Ground-Based Radar (GBR)[2]	2.7	3.1	+0.4	+15%
System Engineering and Integration (SE&I)	7.8	5.0[1]	-2.8	-36%
Launch	8.3	8.6[1]	+0.3	+4%
Performance Reserves[3]	0	1.1	+1.1	N/A
TOTAL	$115.4	$69.1	-$46.3	-40%

[1] SDIO estimates.

[2] GBR is currently under consideration for inclusion in Phase I.

[3] A performance reserve is allocated to allow for additional capability expansions if required to meet a changing threat. The management reserve imbedded in the estimate exceeds 10 percent for both development and production phases. This reserve is a key part of stabilizing costs in a changing technology and threat environment.

Interceptors

The two interceptors in the SDS Phase I architecture are the space-based interceptor (SBI) and the ground-based interceptor (GBI).

SBI. The SBI element had most dramatic acquisition cost reduction: $34.3 billion (1988 dollars), or 66 percent, from the June estimate. Studies indicated this element could meet its performance requirements with fewer interceptors and carrier vehicles if interceptor velocity could be increased. Advances in focal plane array technology for seekers allow a lighter "front-end" and make it feasible to resize the rocket motors, thereby increasing the velocity, range, and effectiveness of the interceptor. Communication and fire control functions, redundant to other SDS elements, were removed from the satellite carrier vehicle, thereby also reducing the equipment cost and development risk. Finally, the SBI carrier vehicle will be the first satellite to be mass produced economically in a way that is more nearly comparable to aircraft or other military system production.

GBI. Increased estimated acquisition cost of $1.0 billion is due to a planned 70-percent increase in GBI inventory, along with related increases in launchers, support facilities, and personnel. However, due to a nonrecurring GBI development cost in the estimate, which is independent of quantity, this equates to only a 21-percent increase in GBI acquisition cost. The net effect is a lower estimated cost for increased capability of the SDS Phase I architecture with fewer SBIs and only a small compensatory increase in the number of GBIs.

Sensors

Studies concluded that the initial architecture contained excessive sensor redundancy. Cost reductions are discussed below, by sensor type, for the Boost Surveillance and Tracking System (BSTS), the Space-Based Surveillance and Tracking System (SSTS), the Ground-Based Surveillance and Tracking System (GSTS), and the Ground-Based Radar (GBR).

BSTS. Acquisition cost reduction for the BSTS resulted from a decrease in planned constellation size and a technical reassessment of the focal plane array. Although there will be a decreased sensing capability of the BSTS constellation, the reduction will not lead to a decrease in military effectiveness. Analysis of the previous architecture showed there was an excess of sensing capability relative to interceptor capability—the sensors could acquire more information than was necessary. The removal of this excess sensing capability reduced estimated BSTS acquisition costs by $1.0 billion.

SSTS. Avoidance of excessive system sensor redundancy also contributed to the estimated SSTS acquisition cost reduction of $3.4 billion (27 percent below the June estimate). Individual satellite capability will decrease because of a reduction in aperture size and in the number of detectors in the focal plane array, along with corresponding reductions in satellite structure, processing, and other subsystems. However, there will be an increase in constellation size to ensure communications. The net effect will be a less expensive system which will continue to support architecture sensing requirements.

GSTS. The GSTS will not experience any significant technical or programmatic changes. The estimated acquisition cost of GSTS declined slightly ($0.3 billion or 8 percent) due to a reduction of flight testing in favor of more ground testing and a reduction in the development effort.

GBR. The GBR experienced a projected cost increase of $0.4 billion (15 percent). The increase reflects new cost data for an upgraded experimental radar: its role will be expanded from a terminal-only sensor to a midcourse and terminal sensor. With this upgrade, it will also provide added capability as a test bed for resolving discrimination issues. Although GBR is not currently approved as an element of Phase I, it is under consideration and is included here for architecture analysis purposes.

Command Center

Major changes in the SDS Phase I operational concept and hardware definition have resulted in a 50-percent reduction of the estimated acquisition cost ($7.3 billion). The key modifications to the hardware definition are (1) some space-based communication functions were reassigned to ground facilities; (2) the size and acquisition strategy for obtaining an SDS fiber optic network changed; (3) estimated real-time software requirements decreased; (4) an airborne command center component was eliminated; and (5) a larger number of existing ground segment command centers are to be used.

SE&I

The estimated SE&I acquisition costs were reduced by 36 percent due to significant changes in the functions of the SE&I segment. These included a reduction of overlapping integration and test software development efforts, a redistribution of integration facilities and hardware, decentralization of training and training software development, and elimination of redundant integration and simulation hardware.

4.1.3 Future Cost Goals

SDIO has prepared many cost reduction reports on various subjects, including thermal control, signal processing, etc., in order to convey cost-reduction opportunities. SDIO will continue to sponsor research that will consider reducing both the costs of systems due to performance requirements and the costs of systems due to administrative and regulatory requirements. The importance of "could cost" will continue to be emphasized. Two ultimate goals are a properly balanced architecture that allocates functions in the most economical way and an industry that efficiently adds value to its products using the most appropriate technology and capital base.

The latest cost estimates reflect SDIO's best assessment of the designs, technologies, and facilities that will be in place when SDS Phase I is acquired. Realizing that challenging objectives motivate exceptional performance, SDIO is also setting cost goals which are lower than today's estimates. To meet these goals, SDIO will continue intensive efforts in cost reduction.

4.2 Technical Progress

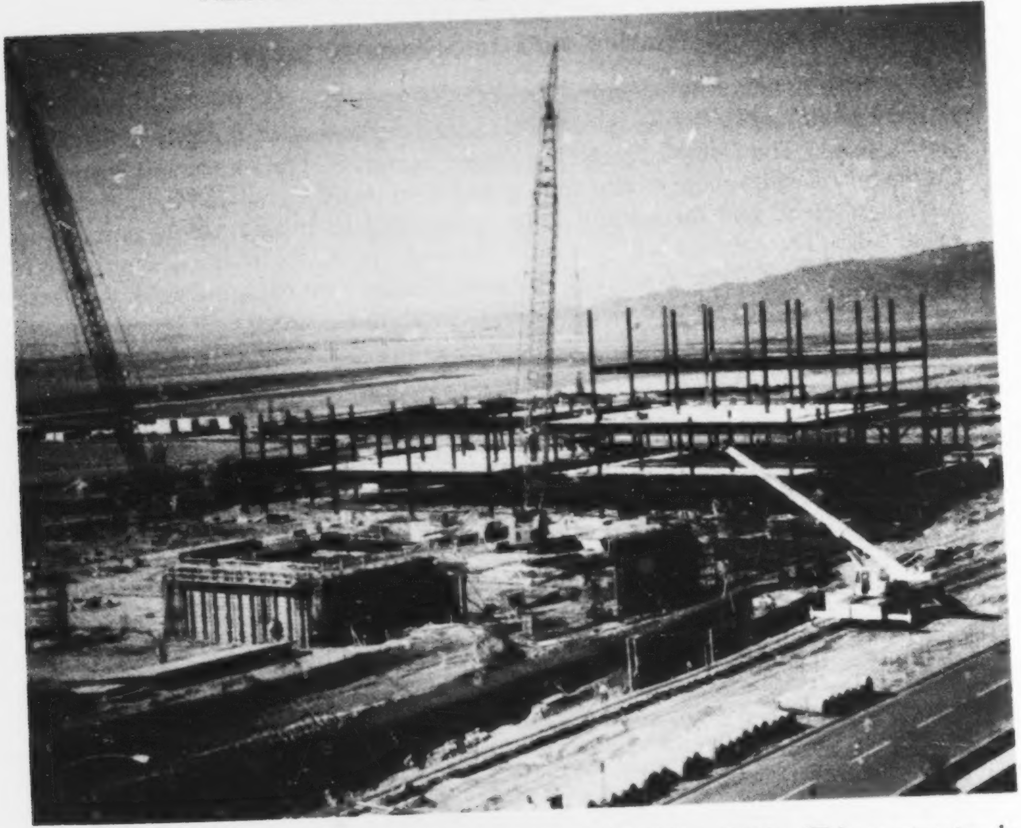
This section discusses SDI technical progress in the following areas: system, boost and post-boost defense, midcourse defense, terminal defense, and command and control.

4.2.1 System Progress

Significant technical progress was made during 1988. Our ability to focus these technical achievements into specific design and architecture changes and estimated cost savings results from the adoption of a system engineering approach. SDIO has established an engineering task force to support this national effort. System engineering provides the discipline for Phase I system optimization and for a realistic evaluation of technical progress and projections.

Progress in developing the system engineering approach during 1988 consisted of establishing two contractor engineering teams. In January 1988, a contractor was selected to provide overall engineering and integration of National Test Bed (NTB) consisting of the National Test Facility (NTF), under construction in Colorado Springs, Colorado (Figure 4-1), and a network of geographically dispersed test facilities. The management definition and acquisition of NTB capability have been centralized to provide an SDS capability that will ensure integrated system testing.

Figure 4-1
National Test Facility (Under Construction)



Second, an SE&I contractor was selected in May 1988. This contractor is charged with developing the overall baseline system design and integrating the component element programs into an effective system.

The two contractor components of the engineering task force are complemented by the not-for-profit Phase One Engineering Team. This triad will support design trade-off decisions.

Additionally in 1988, a Software Center (SC) was defined to establish software policy and make the investment in software tools that will allow development of efficient software. The SC will provide trusted software tools that reduce risk and enable each component element to capitalize on investment in the total software environment.

4.2.2 Boost and Post-Boost Defense

Recent advances in technology that can be used to intercept an attacking missile in its boost and post-boost period have been significant. Two major challenges are early interception of boosters and post-boost vehicles to prevent deployment of buses, reentry vehicles, and decoys and assured space-based defensive element survivability. Progress in meeting these challenges is occurring for sensor and interceptor elements approved for Phase I of the strategic defense system and for candidate elements under consideration for follow-on phases.

BSTS

Two noteworthy accomplishments this past year for the Phase I boost layer sensor system are in radiation-hardened signal processing and producibility of focal plane arrays. The Generic Very High Speed Integrated Circuit (VHSIC) Spaceborne Computer (GVSC) successfully demonstrated on-board signal and data processing at sufficient speed and throughput rates to accomplish mission requirements. (See Table 4-2.) The satellite will use and communicate the information needed by other elements of the defense system. Moreover, it is the first data processor to meet SDI standards for radiation hardness of the total spaceborne computer. A second example is the advancement in producibility of mercury cadmium telluride (HgCdTe) focal plane arrays operating in the medium-wavelength infrared (MWIR) region. Passive detection from approximately geosynchronous altitude of hot missile plumes, against cluttered backgrounds, requires a large focal plane array with thousands to millions of pixels. Significant progress has been made this past year in understanding ingot growth processes for HgCdTe, an inherently radiation-hardened material, and in control of manufacturing techniques. The MWIR detector Manufacturing Technology program has resulted in projected cost reductions and a production rate increase.

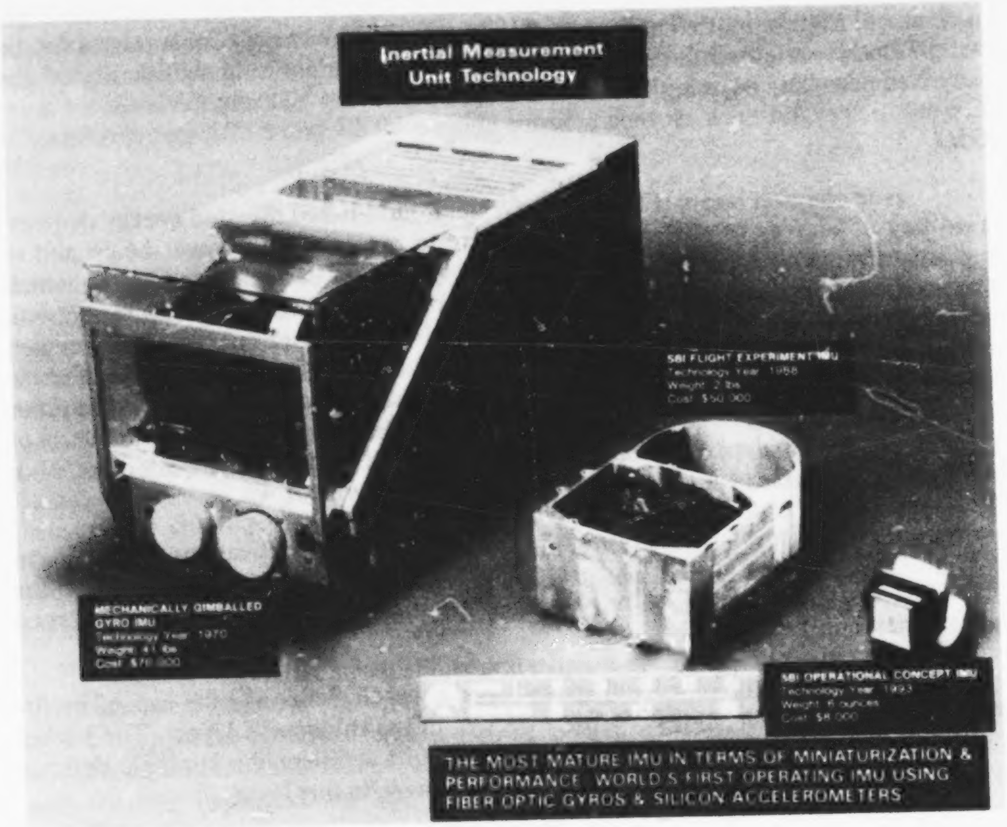
Table 4-2
Space Processor Evolution

Feature	Advanced Digital Operations Processor	Airborne Optical Adjunct	Generic VHSIC Spaceborne Computer
Size	4.5 ft^3	2.0 ft^3	0.25 ft^3
Weight	130 lbs	130 lbs	12 lbs
Power	1 kw	1 kw	80 w
Environment	Lab	Flight	Space
Throughput	3 MIPS	3 MIPS	15 MIPS
Radiation Hardness	Non-Rad-Hard	Non-Rad-Hard	SDI Standard

SBI

Two major advances related to space-based interceptors have occurred in propulsion and navigation technology. Since 1987 the propulsion thrust-to-weight ratio has increased greatly in axial propulsion engines. This is significant because interceptors with high-thrust, fast-burn motors can react to threats more quickly and, also, more interceptors can attack boosters in a given period of time from an orbiting platform. A miniaturized navigation device for guiding the interceptor to a booster has also been demonstrated to satisfy operational conditions. This device, an inertial measurement unit (IMU), is a substantial reduction in size from comparable devices used today, and has capabilities for measuring interceptor acceleration that today's larger units do not have. (See Figure 4-2.) These IMUs have significant potential for use in future missiles and aircraft outside the SDI Program, both militarily and commercially.

Figure 4-2
Inertial Measurement Unit Technology


Inertial Measurement
Unit Technology
SBI FLIGHT EXPERIMENT IMU
Technology Year 1988
Weight 2 lbs
Cost $50 000
MECHANICALLY GIMBALLED
GYRO IMU
Technology Year 1970
Weight 41 lbs
Cost $70 000
SBI OPERATIONAL CONCEPT IMU
Technology Year 1993
Weight 6 ounces
Cost $8 000
THE MOST MATURE IMU IN TERMS OF MINIATURIZATION & PERFORMANCE. WORLD'S FIRST OPERATING IMU USING FIBER OPTIC GYROS & SILICON ACCELEROMETERS

Advances are also continuing in alternative SBIs, such as "Brilliant Pebbles," with built-in sensors, navigation components (a star tracker with a wide field of view), and sufficient on-board power and signal and data processing for assured performance.

This star tracker and processing capability enable an interceptor to function both as an interceptor and as the support platform all within one package. Placing many such single interceptors in space greatly enhances survivability. Brilliant Pebbles technology was demonstrated in ground tests in 1988 and will be demonstrated in a flight experiment in 1989. Cost reductions for space basing of such interceptors could make it possible to acquire large numbers and provide a highly effective first defense layer.

SBL

Soviet efforts to counter the capabilities of early kinetic energy interceptors can be nullified with speed-of-light lasers now under consideration for follow-on phases of the SDS. The Alpha chemical laser, now in the final stages of assembly, will provide a test of space-based laser technology in a large space simulation chamber. Lasing tests are scheduled for spring 1989. The power to be obtained in the Alpha tests is within an order of magnitude of the power level required for booster destruction. These tests are expected to confirm that Alpha technology can scale up to minimum operational power requirements. The potential for the space-based chemical laser element has been further enhanced this year by the successful acceptance testing of LAMP—the first large, segmented, flight-qualified active mirror of its type. The shape of this mirror can be continuously varied while the laser fires, thereby maintaining the quality of the projected beam and ensuring its effectiveness in destroying boosters.

GBL

Free electron lasers (FEL) can provide ground-based directed energy devices. Two key objectives of SDI FEL research are to create a high-power beam and to propagate it through the atmosphere. The program has demonstrated lasing which shows wavelength scaling beyond that needed for an operational system. In addition, successful operation of the world's longest "wiggler" magnet (25 meters) has provided answers to many technical issues in the area of scalability of a crucial component of the FEL to create high-power beams. Laboratory experiments have shown that three times the predicted laser power can be propagated through the atmosphere before the onset of thermal blooming instability. This allows the use of smaller beam directors, with associated reductions in cost and risk.

The FEL also affords significant potential for medical applications. The medical FEL (MFEL) program, which Congress funds through the SDIO, also draws on the resources and expertise of 21 universities, 2 national laboratories, 2 commercial laboratories, and 1 teaching hospital.

Both the ground-based and space-based laser elements add the capability for interactive discrimination of RVs from decoys in the midcourse layer. The highly capable sensors and large optics they require could augment the strategic defense system's capabilities for passive discrimination, as well, in that layer.

Neutral Particle Beams

A third follow-on phase technology for destroying boosters and performing interactive discrimination, and potentially for destroying RVs, has advanced substantially in the last year. The Neutral Particle Beam (NPB) program has demonstrated two forms of high-energy accelerators—the ramped gradient and the cryogenic drift tube linear accelerator. The Accelerator Test Stand at Los Alamos National Laboratory has been upgraded to higher energy to demonstrate scaling toward operational system parameters. The Beam Experiment Aboard Rocket (BEAR) flight is now assembled. This flight will demonstrate NPB operation in space.

Magnetic optic devices to steer and focus the beam continue to make important progress. SDIO has demonstrated these devices at beam energies that show promise of scaling up to an operational system. A foil neutralizer which produces an electrically neutral beam (so that the beam will not be deflected by the earth's magnetic field) has also been successfully tested with these parameters.

4.2.3 Midcourse Defense

The greatest technological challenge in the midcourse region is discrimination of RVs from a variety of other objects, including decoys and debris. The Midcourse Sensor Study, conducted by SDIO during the past year, established the discrimination capability that will be required for an SDS Phase I. The study concluded that a complement of active and passive sensors would be required for the midcourse and led to a recommendation that the GBR be considered for inclusion in the SDS Phase I. Complementary SSTS and GSTS passive infrared sensors were retained in the SDS Phase I.

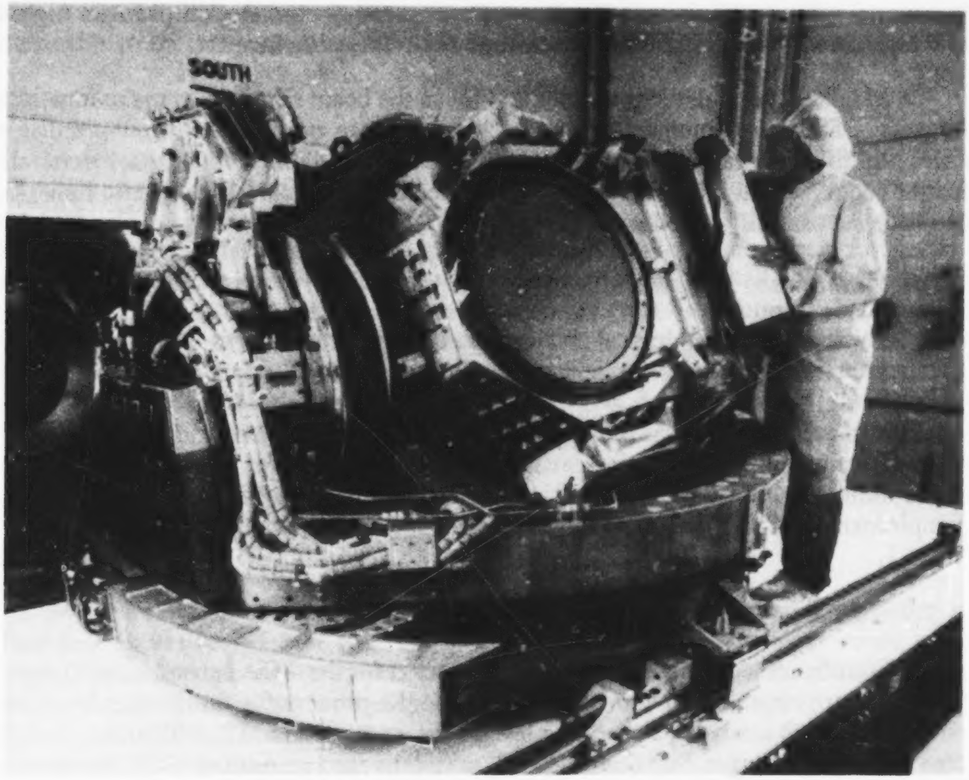
SSTS/GSTS

Significant technical achievements occurred for the AOA sensor, arsenic-doped silicon impurity band conductors (IBCs), and in the process for fabricating beryllium mirrors. The AOA sensor, a scanning long-wavelength infrared (LWIR) sensor of the same type to be used in SSTS and GSTS, was delivered in August 1988 for use as a major SDI test bed. Specifically, the test bed provides a signal processing capability of approximately 20 times that of the current Airborne Warning and Control System (AWACS). This allows the finding and processing of thousands of targets. This test bed demonstrates the technical feasibility of a complex, wide-field-of-view LWIR sensor and will demonstrate tracking and discrimination functions against large numbers of midcourse targets. It also establishes confidence in the operation of later spaceborne LWIR sensors at a greatly reduced cost and provides the ability to continue testing from an airborne platform. The AOA sensor is shown in Figure 4-3.

Silicon IBCs offer survivability and extreme sensitivity as midcourse detectors. They can be produced at one-ninth the cost of mercury cadmium telluride focal planes, which require much effort to produce for longer wavelengths. The producibility advance is that, for the first time, silicon focal planes can be mated to silicon electronics and thereby capitalize on and open new opportunities for the mature silicon manufacturing capabilities in this country.

Beryllium mirrors have been developed and tested that meet, and in some cases exceed, the allowable deformation during and after threat-level X-ray exposure. Beryllium is an inherently hard material against X-ray fluences because of its low

Figure 4-3
AOA Sensor



atomic number. In addition to producing mirrors for GSTS that reduce the equivalent optics weight by one-half, the new fabrication process reduces manufacturing costs by using a new agent to separate a mirror from its mold. This new agent reduces by 25 percent the labor-intensive manufacturing cost to polish the mirror. Finally, the new process takes into account the extreme toxicity of beryllium and fully addresses environmental safety issues.

GBR

The area of greatest progress this year has been in bulk filtering and microdynamic discriminant algorithm development and validation using several systems. Furthermore, discrimination techniques using real-time data obtained through earlier collection efforts have been developed to optimize discrimination performance. These efforts will give GBR the ability to use its millimeter range resolution capability against the microdynamic behavior of an RV to discriminate RVs from a variety of other objects, including decoys and debris in the midcourse region. Furthermore, GBR is making significant progress toward meeting its design specification frequency, which, unlike the Safeguard UHF radars, will enable it to function virtually without interruption in a nuclear environment. In addition to the midcourse defense, the GBR will be the principal tactical active sensor designed to operate in the early terminal defense.

GBI

Steady advancement continues on schedule with the midcourse interceptor. A capability for in-flight cooling of the ERIS focal plane array was demonstrated. This capability is a major factor in providing a low-cost (dormant) seeker by reducing ground support costs. Chamber tests of the seeker are ongoing using a simulated background and scene.

Next-generation technology is also advancing to provide preplanned GBI upgrades. The Lightweight Exoatmospheric Projectile (LEAP) is an example of a program to integrate interceptor sensor, navigation unit, data processor, and propulsion technologies.

A focal plane array with twice the number of pixels, as compared to current tactical guided interceptors, has been integrated with wafer-scale packaging to a signal and data processor that can fit in the palm of a hand and has the equivalent capacity of a Cray computer. American miniaturization technology has produced a lightweight projectile. Emphasizing these advances, Figure 4-4 compares the new with the old generation of technology. These miniaturized projectiles now have the capability to address the threat scenarios of the midcourse, as well as the boost and post-boost layers of the SDS.

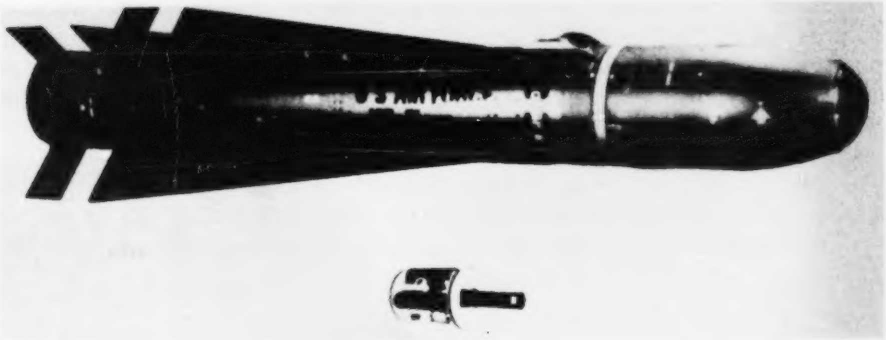
4.2.4 Terminal Defense

This section discusses technical progress in the High Endoatmospheric Defense Interceptor (HEDI) and the hypervelocity gun (HVG).

HEDI

The shortness of the terminal period and effects of the atmosphere pose the major technical challenges for terminal defense interceptors which are under consideration for follow-on phases of a strategic defense system. Two particular problems are (1) the heat generated by flight in the atmosphere and (2) the maneuverability required for a "hit-to-kill." For the first time, new platelet technology enables production of 11-pound divert-thrust motors which achieve 10,000 pounds of thrust. This thrust performance compares roughly to the motor used on the Apollo Lunar Lander, which weighed 392 pounds. As HEDI travels through the atmosphere, the surface of the vehicle will become extremely hot. Sapphire windows have been developed which will enable an infrared sensor inside the HEDI to see through the hot window and still detect the heat from the nuclear reentry vehicle, thereby enabling successful interception. Sufficient progress has occurred in this project that the first of a series of experimental flight tests will occur soon.

Figure 4-4
Integration Projectile



This figure shows the advances in technology attained by the LEAP program. The new technology (illustrated by the small projectile on the lower part of the figure) has a major reduction in size and weight as compared to the front portion of the older Maverick missile (shown on the upper part of the figure).

HVG

Hypervelocity guns could provide terminal defense by using a high firing rate of large inventories of inexpensive projectiles. The relatively high capitalization cost of each terminal HVG site is offset by the low cost of the projectiles and a capability to engage a large number of incoming warheads. This concept is very robust to structured attacks, penetration aids, and saturation techniques. The most significant achievement this year is to provide the world's largest pulse power facility, thereby reducing costs for experimental testing of HVG concepts.

4.2.5 Command and Control

Integration of the human decision-maker and the automated battle management system is under active investigation using the EV88 Decision Aids Test Environment (DATE) and NTB war game simulations. Initial experiments were conducted during the first quarter of FY 1989 and used military personnel with command center and/or command experience. The SDS commanders are trained to interface with the SDS simulations under peacetime and major attack scenarios.

These experiments, using direct man-machine interactions, were conducted to promote understanding between the organization developing the SDS and the users who will operate the system. The critical timing of the SDS commander's decisions in the experiments, whether acting as the primary or alternate commander, is a driving function for overall defense effectiveness. The operators evaluated the data displays, as well as data relevancy and availability, to include the need for data to support higher authority and other defense community information needs. The developers evaluated how multiple SDS commanders responded to the same situations to establish a statistical data base for defining processing speed and display requirements and for describing how SDS commanders reacted to unannounced changes in SDS element availability during the engagement period.

The SDS commanders in the experiments were able to assess the situation and command the system to release defensive interceptors in accordance with direction from higher authority in sufficient time to engage boosters under the scenario conditions. As a result of these experiments, the SDS commanders have made specific recommendations regarding the need for more refined commander authority specifications, command center procedures, data requirements, and further refinement of the experimental rules of engagement. The developers have established baseline human performance parameters, learned command center procedures, and established a statistical data base for information requirements needed to support deliberate and considered human decisions. These lessons are being integrated into the DATE and NTB simulations.

Chapter 5

System Projects

CONCEPT SIMULATION

Humans will remain in control of the strategic defense system as shown in the above photo of a simulated command center environment.

Chapter 5

System Projects

A major objective of the SDI Program is to preserve near- and long-term defensive options. Recent SDI achievements, described in this chapter and in Chapter 6, have answered many of the early technical questions associated with these options. We are confident that remaining key technical issues can be resolved to support a decision on whether to proceed with the development of a strategic defense system (SDS).

One noteworthy accomplishment on the way to demonstrating how these remaining key technical issues will be resolved occurred this past year: the SDS Test and Evaluation Master Plan (TEMP) was approved in March 1988. The TEMP consists of a capstone document with annexes that address pertinent SDS test and evaluation issues, software, security, survivability, supportability, the National Test Bed, and supporting technologies. In addition to these annexes, TEMPs for SDS Phase I elements and test and evaluation summaries for potential follow-on elements and supporting programs are included as appendices to the SDS TEMP. The FY 1989 annual update to the SDS TEMP was completed on 30 November 1988.

SDS Phase I elements are currently in the demonstration and validation (Dem/Val) stage. The primary methods of Dem/Val for system concepts are simulation, laboratory ground test, and limited flight testing. The three key objectives during Dem/Val are (1) to ensure a top-down integration of system and element test requirements, (2) to perform a bottom-up validation of performance through technology and element testing, and (3) to accomplish modular and early system integration testing. Early system integration testing such as SATKA Integrated Experiments (SIEs) and Near-Term System Integration Test and Evaluation (NSITE) has occurred. These tests will be followed by dedicated integration tests in cooperation with other element test activities using more capable hardware.

Candidate follow-on elements that have potential for responding to an evolving threat are in the concept definition stage. During FSD both developmental and operational tests will be conducted on the SDS Phase I and its elements. Early operational assessment will also begin on follow-on elements before and during their integration into an SDS. As SDS elements enter the production and deployment phase, test and evaluation will continue. Feedback from tests will provide data to the system engineering and element developers for incorporation in future designs.

The rest of this chapter summarizes each current system research project by presenting an overview of the concept and project, an understanding of the technology, accomplishments during the past year, and future plans.

Section 5.1

System Engineering Projects

5.1 System Engineering Projects

System engineering generates the system baseline designs, performs element and inter-element trade studies, and produces specialty engineering analyses.

5.1.1 Phase I System Engineering

The Phase I system engineering program will develop a balanced SDS design using a disciplined and documented engineering process to allocate requirements between defensive system elements and to develop command center design requirements. The primary goal is to integrate element concepts, technology requirements, and architecture studies into an affordable system design. System requirement analyses (SRA) address the five functional areas: mission operations, logistics and support, deployment, production, and test, which must be analyzed to define and develop the SDS and element specifications.

System Engineering Objective

The objective of the SDS system engineering effort is to ensure the SDS design reflects a technically feasible, affordable, secure, and testable ballistic missile defense system with human-in-control. Integration of system elements is required to meet the overall SDS objective. While the emphasis of this activity is on Phase I, analyses of integration issues are being conducted for the follow-on phases. Some of the more critical SDS Phase I issues include sensor-to-sensor correlation, discrimination of the lethal threat from decoys and debris, guidance updates for interceptors, and Command Center/System Operation and Integration Functions (CC/SOIF) interface capability.

System Design Baselines

Initial versions of the system specification will be available in 1989. The SDS Phase I functional baseline consists of the SDS system-level specification and documents governing interfaces among the SDS elements and between the SDS and external systems. All changes in the baseline affecting the allocated SDS functional or performance requirements are approved by an SDS Configuration Control Board (SCCB) and incorporated into the system-level specifications.

Accomplishments and Future Plans

In May of 1988 a system engineering and integration (SE&I) contractor was competitively selected to perform the System Engineer (SE) function. The SE ensures effective integration of the element programs and establishes a signal design framework for the SDS. The SE is currently in the process of accomplishing the SRA and drafting element and interface requirements specifications. These documents constitute the system/element interface framework and will be available in March 1989. Additionally, the SE is developing a system-wide test program using existing and projected test resources to validate the Phase I system design.

The SDS Phase I System Engineering is a team effort. The team members include the SE, the Phase One Engineering Team and R&D laboratories, the element programs, and the resources of the National Test Bed. Current issues being addressed include (1) midcourse sensor requirements, (2) SBI and GBI interface requirements, (3) preferential/adaptive defense performance, (4) system and component survivability, (5) critical functional sequences and timelines, and (6) command and control trades.

A threat has been developed that allows the SDS to be evaluated against a variety of stressing scenarios. The evaluation of the current SDS against this threat spectrum will allow the selection of a system "design-to" point.

The Software Center of Excellence (SCOE) has been defined where software capability will be collected and software policy enforced. The Computer Resources Management Plan and the Software Development Plan, containing software policy and software issue resolutions for the Phase I SDS program, will be published during 1989.

The command center element presents a unique set of challenges. Command center requirements are derived from the JCS mission requirements for the system and the (USSPACECOM) concept of operations. In FY 1989 a Command Center Description Document detailing the command center element requirements and development plans will be published.

5.1.2 Specialty Engineering Integration

Specialty engineering consists of four major efforts: (1) integrated logistics support (ILS); (2) environmental impact analysis process; (3) industrial base and producibility efforts; and (4) reliability, availability, and maintainability (RAM) efforts.

Integrated Logistics Support

The management objective of the ILS program for SDS is to ensure that the SDS elements will be supportable throughout their life cycle. An Integrated Support Working Group (ISWG) has been chartered by SDIO to organize an infrastructure of military, agency, and contractor authorities on supportability. Integrated Logistics Support Plans (ILSP) are being developed to provide a comprehensive structure and schedule for logistics at the system, service, and element levels. Logistics support analyses (LSA) will be performed to determine the logistic resources required to support SDS, and to assess the supportability of the SDS and its elements.

Environmental Impact Analysis Process

There are two components of the SDIO Environmental Impact Analysis Process (EIAP): environmental planning and environmental documentation. Environmental planning ensures designs and proposed actions will minimize impacts to the environment when possible. Environmental documentation is prepared for each major proposed action which might affect the quality of the human environment.

Industrial Base and Producibility Efforts

Investigation and validation of numerous SDI technologies include the capability of United States industry to employ these technologies in an efficient and affordable manner. The lead times required to implement improvements needed for any SDS FSD or production decision drive the producibility program. Objectives of the program are to (1) develop and establish a manufacturing/producibility strategy, (2) assure that producibility, affordability, and supportability considerations are major players in the development of an SDS, (3) develop and establish Manufacturing Operations Development and Integration Laboratories (MODILs), and (4) assure that an adequate and responsive industrial base is available to support the SDS.

Manufacturing and Supportability Strategy. The SDIO manufacturing strategy is based on early initiation and execution of a series of DOD, Army, and Air Force industrial base investment and producibility improvement programs. This is an iterative process whose objective is to raise industrial base capability/producibility/manufacturing technology issues and risks early in the SDS program. Efforts are ongoing in areas such as detector, optical systems, extremely high-frequency communications, solar cells, and space power systems.

MODILs. In concert with SDIO advanced product development, MODILs develop advanced processing and manufacturing technologies (including automation) to gain substantive increased productivity in modern factory layouts.

The first MODIL was established at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, and has as its mission the development, validation, and transfer of technologies to produce survivable optics for SDIO. The Survivable Optics MODIL is a series of projects being orchestrated by ORNL that are executed by the United States optics industry, government labs (both DOD and DOE), and universities. The majority of FY 1989 projects will be open to observation and participation by U.S. industry. Other producibility areas are being evaluated for MODIL applicability. An immediate example is a MODIL to address the manufacturing issues of advanced sensors employing focal plane arrays.

The single-point turning machine at Oak Ridge National Laboratory, shown in Figure 5.1 -1, represents current machining technology used by the optics industry. The Survivable Optics MODIL will work to advance technologies that can be employed to increase the accuracy of the machining process, including on-process metrology, and address machining of difficult materials such as beryllium. The MODILs established by SDIO will be a critical element in enhancing the overall affordability of SDS system elements.

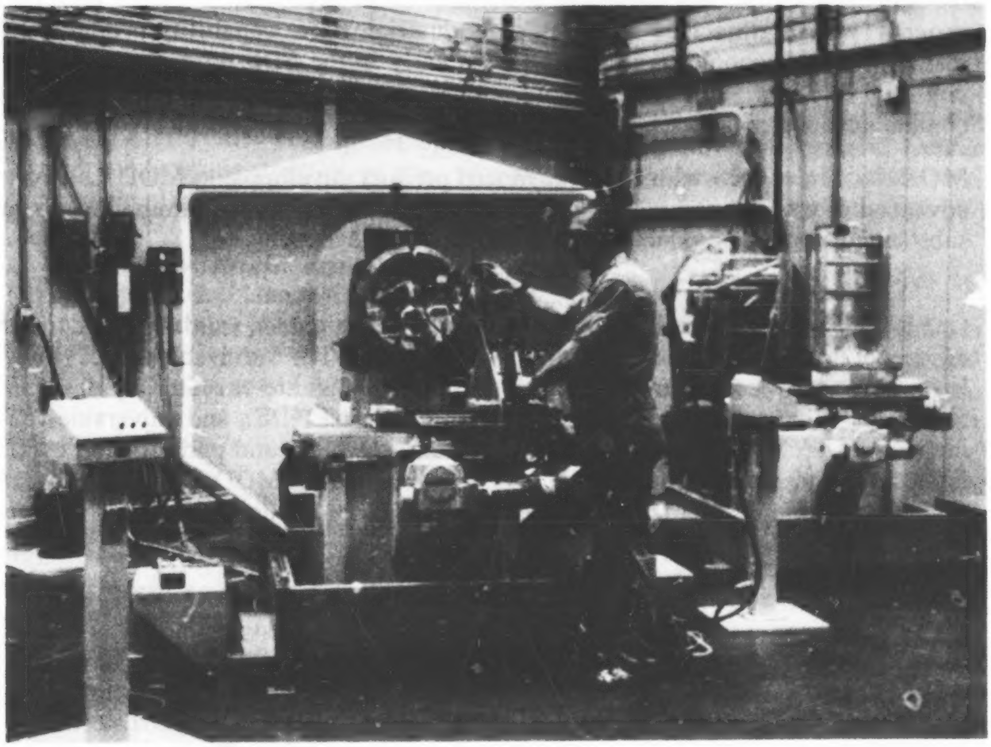
Reliability, Availability, and Maintainability

Achieving the readiness requirements necessary to provide for SDS availability at least cost is the function of RAM activities. Threat assessment, support concept, mission dependability, cost, and engagement models are available and/or in development to relate RAM to both mission effectiveness and cost. This family of models will provide the capability to determine the optimum distribution for any given threat, to analyze the effect of a change in the threat assessment, and to conduct tradeoff analyses.

5.1.3 Test and Evaluation

The goal of the test and evaluation (T&E) activities is to demonstrate that the system is effective, survivable, and operationally suitable. SDS Dem/Val testing has three objectives: (1) demonstrate and validate a feasible system design, (2) reduce risk by demonstrating integration of enabling technologies, and (3) structure the required system integration test capabilities.

Figure 5.1-1
Single-Point Turning Machine



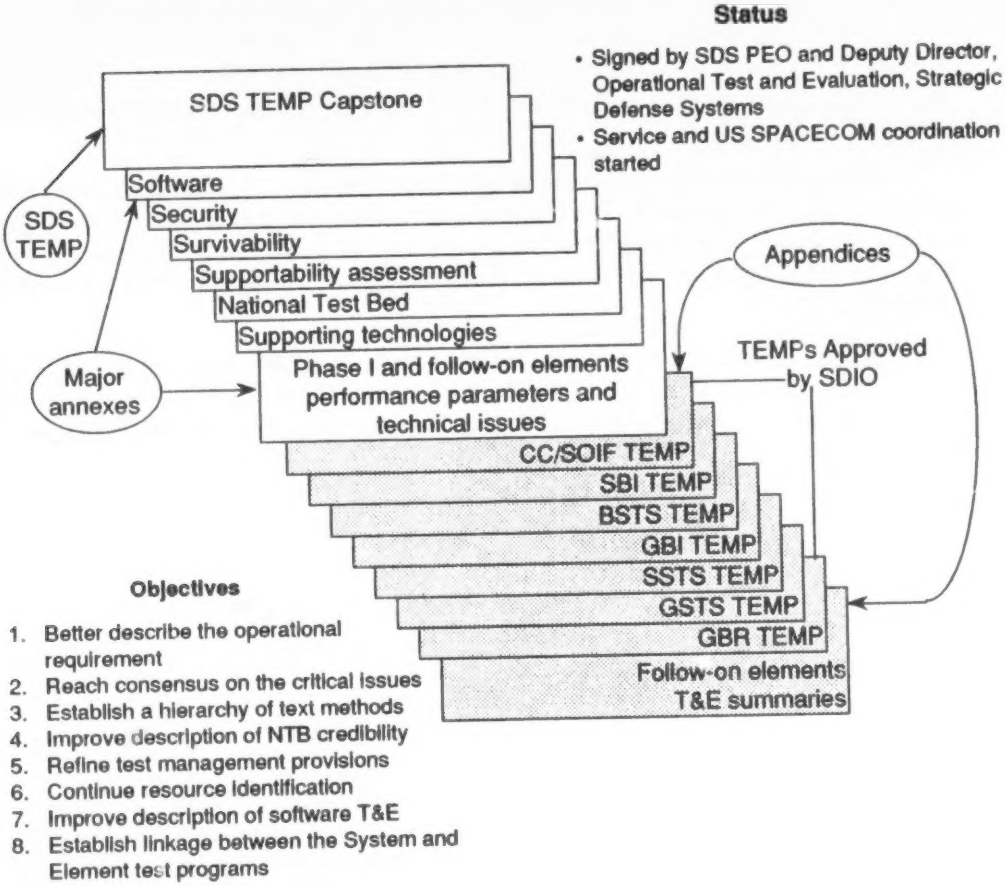
Overview

The primary methods of Dem/Val for system concepts are simulation, laboratory ground test, and limited flight testing. The three key objectives during Dem/Val are to (1) ensure a top-down integration of system and element test requirements, (2) perform a bottom-up validation of performance through technology and element testing, and (3) accomplish modular and early system integration testing.

Test and Evaluation Master Plan

The SDS Test and Evaluation Master Plan (TEMP) was approved in March 1988. The TEMP consists of a capstone document with annexes that address pertinent SDS test and evaluation issues, software, security, survivability, supportability, the National Test Bed, and supporting technologies. In addition to these annexes, TEMPs for SDS Phase I elements and T&E summaries for potential follow-on elements and supporting programs are included as appendices to the SDS TEMP. The FY 1989 annual update to the SDS TEMP was completed on 30 November 1988. Objectives of the update are shown in Figure 5.1-2.

Figure 5.1-2
FY 1989 Update of TEMP Concept Objectives and Status


SDS TEMP Capstone
Software
Security
Survivability
Supportability assessment
National Test Bed
Supporting technologies
Phase I and follow-on elements performance parameters and technical issues
CC/SOIF TEMP
SBI TEMP
BSTS TEMP
GBI TEMP
SSTS TEMP
GSTS TEMP
GBR TEMP
Follow-on elements T&E summaries
SDS TEMP
Major annexes
Appendices
TEMPs Approved by SDIO

Status

- Signed by SDS PEO and Deputy Director, Operational Test and Evaluation, Strategic Defense Systems
- Service and US SPACECOM coordination started

Objectives

1. Better describe the operational requirement
2. Reach consensus on the critical issues
3. Establish a hierarchy of text methods
4. Improve description of NTB credibility
5. Refine test management provisions
6. Continue resource identification
7. Improve description of software T&E
8. Establish linkage between the System and Element test programs

The TEMP describes how system performance requirements were used to establish test program objectives. Test performance criteria are being developed to quantify thresholds for system-level testing. These test objectives and performance criteria form the basis for detailed development and operational test planning. In parallel with and subsequent to element level testing, system testing must be performed on the interacting elements, integrated layers, and the complete SDS Phase I.

The key to optimizing the T&E program lies in allocation of system issues to the element test programs. Element-level testing activities must support the resolution of top-level questions of system effectiveness, survivability, and operational ability as well as technical feasibility.

Multi-element integration tests facilitate the development of confidence in performance capability and the reduction of risk for entry into FSD. An incremental buildup of confidence is based on the increasing level of maturity of the test article and test capability. During Dem/Val, analysis, simulation, and ground testing of element component brassboards will be primary evaluation techniques. In addition, early system integration testing such as SATKA Integrated Experiments (SIEs) and Near-Term System Integration Test and Evaluation (NSITE) was performed. These tests will be followed by dedicated integration tests or in cooperation with other element test activities.

During FSD both developmental and operational tests will be conducted on the SDS Phase I and its elements. Early operational assessment will also begin on follow-on elements before and during their integration into an SDS. As SDS elements enter the production and deployment phase, follow-on test and evaluation (FOT&E) will be conducted.

Independent initial operational test and evaluation (IOT&E) and FOT&E will continue to test and evaluate the system and elements. Feedback from these tests will provide data to the system engineering and element developers for incorporation in future designs.

Section 5.2

Sensors, Command Center, and System Operation and Integration Functions Projects

5.2 Sensors, Command Center, and System Operation and Integration Functions Projects

This section describes the concept, accomplishments, and future plans of sensors, command center, and system operation and integration functions projects (specifically BSTS, midcourse sensors, GBR, and CC/SOIF).

5.2.1 Boost Surveillance and Tracking System

This section describes the BSTS concept and discusses its accomplishments and future plans.

Concept and Project Overview

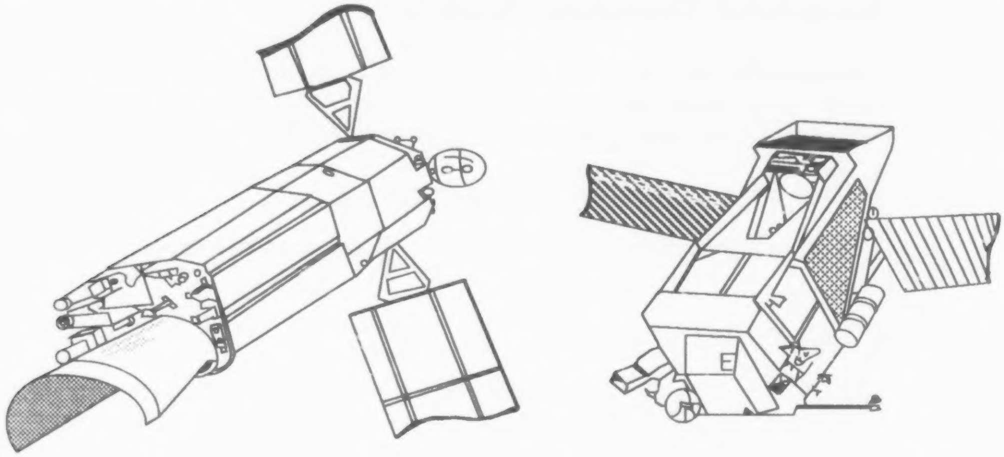
The BSTS is a missile launch warning system that detects launches, identifies boosters, and predicts the booster track of intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs) during their powered flight. Deployed in a high earth orbit for optimum viewing and survivability, the BSTS uses advanced sensors and processing techniques to track missiles by observing the missiles' hot exhaust plumes. Advanced on-board data processing capabilities determine missile position and velocity.

As a result of the requirement to maintain this nation's early warning capability and the applicability of sensor technologies in SDI to this essential mission, the BSTS program is scheduled to enter full-scale development in FY 1990. The first FSD vehicle will perform at least an early warning mission. Whether or not any of the capabilities listed herein for BSTS, in addition to early warning capabilities, will be included in that vehicle will be decided later.

The BSTS constellation has the primary responsibility to provide strategic and tactical engagement information as well as to alert status changes to all SDS elements during boost and post-boost engagements. The satellite performs on board analysis. The results of this analysis and missile tracks are transmitted to other sensor elements and ground entry points.

The BSTS, in its demonstration and validation phase, has two prime contractors developing competing system concepts shown in Figure 5.2-1. A single contractor will be selected to proceed with full-scale development (FSD) and initial constellation production. The resolution of key issues will be demonstrated during Dem/Val by individual technology demonstrations and in an end-to-end ground demonstration. During FSD, remaining technical and operational issues will be addressed by continued ground demonstration, a flight experiment and the flight test of the first FSD vehicle. Once in production, the BSTS will be updated through block modifications and improvement programs.

Figure 5.2-1
Two Competing BSTS Concepts



Technology Understanding

Critical to the success of the BSTS mission are focal plane arrays, large optics technology, signal/data processing developments, and background/target phenomenology.

BSTS sensor design requires a complete knowledge of boost-phase phenomenology. This phenomenology is composed of three principal components: (1) the signature of the burning boosters, (2) the characteristics of the natural IR background, and (3) the characteristics of the enhanced IR background created by nuclear detonations. An extensive library of data exists; however, the BSTS will be operating at sensitivities beyond this data base. Planned target signature and background experiments are critical for sensor design, calibration, and algorithm development.

Experiment and measurement programs supporting the BSTS include the Visible Ultraviolet Experiment (VUE) and Shuttle payload missions, such as Starlab, CIRRIS, and the Infrared Background Signature Survey (IBSS). These experiments will augment a portion of the data necessary to measure plume signatures and backgrounds over extended wavelength regimes and to evaluate satellite tracking.

BSTS detects the radiation emitted by the missile using IR detectors assembled into focal plane arrays (FPA). The number of detectors required for BSTS FPAs are an order of magnitude greater than for the current system. The FPAs must be survivable in a radiation environment. Because of its sensitivity and inherent radiation hardness, mercury cadmium telluride (HgCdTe) FPAs are being considered. Pilot lines and laboratory fabrication experiments have identified and are currently addressing key issues in both fabrication and production. Producibility initiatives have demonstrated cost reductions of up to approximately three orders of magnitude.

The producibility of lightweight, 1-meter class, steep aspheric, high optical quality, radiation-hardened mirrors has not yet been demonstrated. Current programs include development of both glass ceramic and beryllium (Be) mirror technologies. Silicon carbide is also being explored, but it is not a mature technology. Survivability requirements make Be a strong candidate material. To date, one Be mirror in this size class has been fabricated, but it does not yet meet the required optical specification. Although fabrication of glassy material has been demonstrated, survivable coatings require extensive development.

Large focal planes generate large data streams which must be processed in real time. Radiation-hardened Very High Speed Integrated Circuits (VHSIC) with large throughput capacity will be needed for real-time signal and data processing. On-board data processing technology requires small, fault-tolerant, low-power, radiation-hardened computers for a lengthy spacecraft mission. The Generic VHSIC Spaceborne Computer (GVSC) is the cornerstone radiation-hardened integrated circuit program. Initial results of GVSC fabrication show very high yields and speeds that exceed specifications. Algorithms to evaluate large threat numbers, and determine individual missile positions and velocities are in development.

Accomplishments

A preliminary review of the BSTS ground demonstration scheduled for FY 1990 and an interim design review (IDR) was conducted.

The VUE hardware was completed and delivered to the system integrator for validation in FY 1990.

In FY 1988, several contractors demonstrated 64K static random access memories (RAMs) that meet and exceed the radiation hardness requirements. Contracts were awarded to develop radiation-hardened linear circuit technology with test data due in FY 1989 and initial high performance parts due during FY 1990.

A producibility program demonstration was conducted for the focal plane arrays required by BSTS in 1988. High production rates and reduced costs (by factors of 10 to 30) for these focal plane arrays were demonstrated.

Future Plans

Efforts will focus on test and demonstration for selection of one BSTS concept, following ground demonstrations.

The BSTS flight experiment will consist of subscale optics and a partial, representative focal plane hosted on a space-based platform. The objective of the flight experiment is to collect real data against real targets from a space environment. The BSTS program will begin procurement in FY 1990 of long-lead items such as mirror blanks, focal plane detectors, and processing chips for the flight experiment and FSD flights. The BSTS will be available for integration in tests of other elements later.

5.2.2 Midcourse Sensors

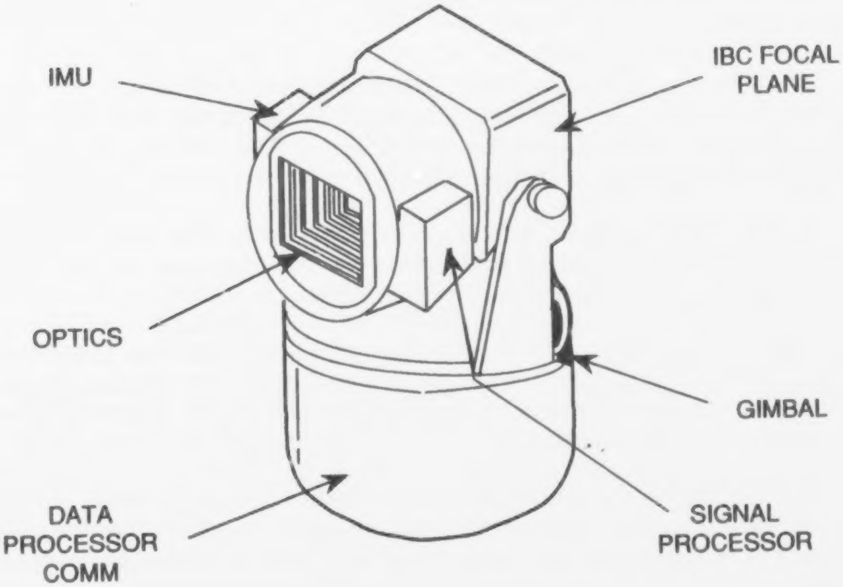
Detection, tracking, discrimination, designation, and handover of targets in midcourse are accomplished by a suite of cooperative sensors. Sensor concepts for the midcourse region consist of the Ground-Based Surveillance and Tracking System (GSTS), and the Space-Based Surveillance and Tracking System (SSTS). The ground-based radar (GBR) is discussed in detail in Section 5.2.3.

Concept and Project Overview

The midcourse sensors (MCS) work together with handoff from BSTS to track offensive ballistic missiles, post-boost vehicles (PBVs), reentry vehicles (RVs), and other objects. Target data, weapon assignment, and fire control in-flight update information from the MCS are transmitted to SBI, GBI, and other SDS elements.

GSTS will be a fast-response, rocket-launched, long-wavelength infrared (LWIR) sensor system boosted into suborbital flight for use in the midcourse layer. Figure 5.2-2 illustrates the GSTS suborbital payload. GSTS enhances strategic defense robustness by providing a reconstitution capability. GSTS launched in pairs or singly with SSTS can utilize multiple LOS (lines of sight) viewing opportunities.

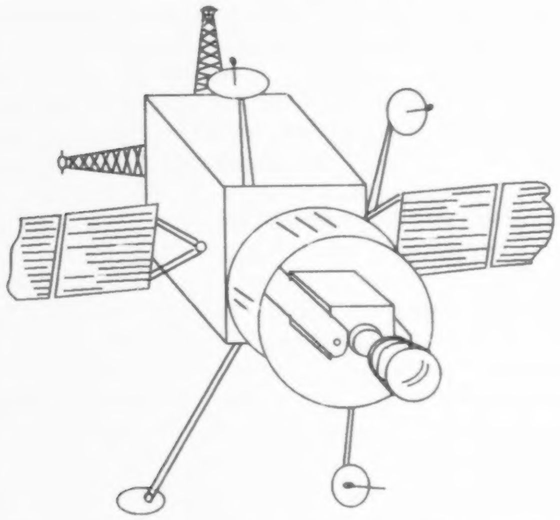
Figure 5.2-2
GSTS Payload



The GSTS sensor will be operationally integrated with SSTS and GBR to provide track and discrimination data. With handoffs from SSTS, the GSTS searches selected corridors, flying close to the threat trajectories, in order to resolve CSOs. Sensor data are processed by ground-based processors. GSTS will be used to cue GBR for objects/clusters requiring further discrimination.

In peacetime, the SSTS will be able to perform valuable foreign target signature collection and satellite tracking functions. The early satellites will gather phenomenological data required for design optimization of surveillance and seeker systems. The general concept for the SSTS is illustrated in Figure 5.2-3.

Figure 5.2-3
SSTS Concept



The SSTS and GSTS and their supporting technology programs are independent but cooperative efforts. The Dem/Val for SSTS and GSTS includes basic system design, end-to-end ground demonstrations of sensors and processors, and flight programs such as Airborne Optical Adjunct (AOA) and the Midcourse Sensors Experiment (MSX).

The GSTS project is developing concepts and multiple sensor designs under a single prime contractor and two sensor subcontractors. A GSTS sensor design will be selected based on critical sensor component technology experiments and sensor test bed results. A flight-qualified payload design will be developed and then fabricated for hardware-in-the-loop ground test demonstrations.

Development of the concepts and design for the SSTS is under way with two prime contractors. The contractors will provide end-to-end ground demonstrations of their concept designs. One concept will be selected and a prototype SSTS satellite system will be fabricated.

Technology Understanding

The principal SSTS/GSTS technical risks to be resolved include sensor optics, focal plane arrays (FPAs), on-board serial and data processing, and cryogenic coolers. Other issues include phenomenology (targets and backgrounds), discrimination of RVs from debris and integration. Manufacturing and producibility issues are significant aspects of the signal and data processors, cryocoolers, large optics, and focal plane arrays.

The SSTS/GSTS will build on the BSTS signal and data processor developments. The more stressing target scenario and natural and nuclear environments require that algorithm performance, processor throughput, fault tolerance, software complexity, and radiation hardening be addressed.

Both midcourse sensors require IR FPAs. Critical issues include noise, speed, power dissipation, radiation hardness, and producibility.

The principal risks associated with optics technology for space-based sensors are the fabrication and assembly of radiation-hardened, large, lightweight mirrors with the required optical properties. Current programs include glass ceramic, silicon carbide, and Be mirror substrate technologies, advanced surfacing technologies, radiation-hard coating technology, and contamination prevention technologies to maintain surface quality over the life of the satellite.

The MCS faces the possibility of having to pick out RVs against natural and nuclear backgrounds. In addition, debris from deployment, tank fragments, and prior intercepts may be present. The emphasis has been on flight programs and laboratory chamber measurements to provide target and background signatures as well as computer modeling.

Accomplishments

In FY 1988 the Midcourse Sensor Study was completed. The GSTS Dem/Val contract was awarded in October 1988. The end-to-end ground demonstrations were planned and initial demonstrations started.

Future Plans

During FY 1989–91 the SSTS/GSTS elements will initiate system design efforts. Technology risk reduction will continue by conducting ground demonstrations of certain critical elements. Development activities for end-to-end demonstrations will continue with the completion of FPA and signal data processor breadboards.

The Airborne Optical Adjunct (AOA) will be used as an early test bed for collecting data relevant to midcourse sensor functions. Flight tests of midcourse sensor elements are planned and will be available for integrated tests with GBI and SBI elements.

5.2.3 Ground-Based Radar

This section describes the GBR project and its accomplishments and future plans.

Concept and Project Overview

The GBR mission will be to provide a late midcourse and high endoatmospheric active sensor system to track and discriminate surviving reentry objects. The GBR became a candidate for inclusion in the midcourse sensor suite, along with the SSTS and the GSTS, based on recommendations of the Midcourse Sensor Study.

The GBR will provide track, search, acquisition, discrimination, and kill assessment functions. In addition, the GBR will accept target handover from other sensors and provides track and homing data for ground- and space-based interceptors. The GBR is a single-faced, X-band phased array radar. It provides enhanced discrimination by measuring the microdynamics of space-borne objects. The GBR's search corridor is based on evaluation of data provided by BSTS and SSTS/GSTS. The GBR can also operate in an autonomous target acquisition mode. Two basing concepts are under consideration: fixed and rail mobile.

Because rail mobility offers a potentially higher level of survivability, it is the baseline approach. To meet mission requirements, a number of mobile radars and their associated support cars could be deployed across the northern CONUS border. The support cars would allow the crew to operate independent of outside support for weeks at a time.

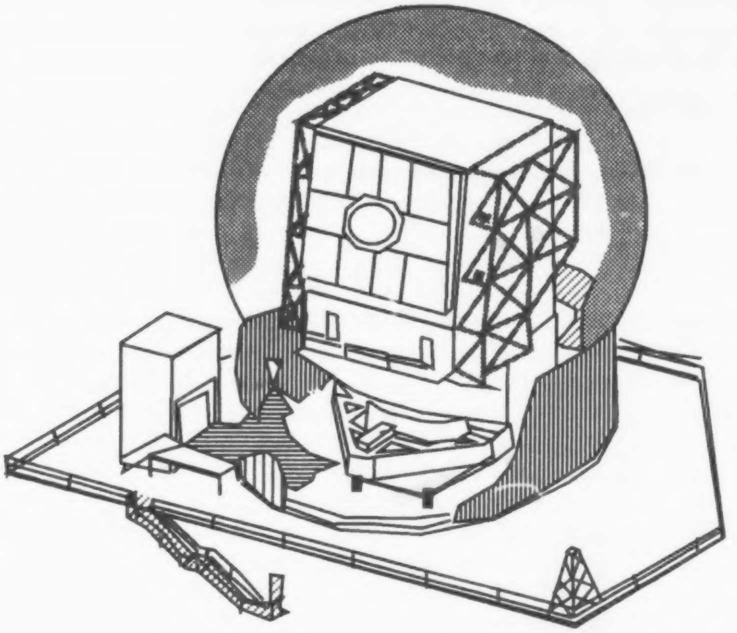
Prior to January 1988, the radar's design goal was to support the terminal phase only. Conversion to support midcourse was accomplished by revising the technical requirements and issuing a change order to the Terminal Imaging Radar (TIR) contract. An experimental system (GBR-X) shown in Figure 5.2-4 will be used to demonstrate GBR technology. As a result of this program approach, the GBR development cycle will be significantly reduced in schedule and cost as compared with a new start.

Concept definition will be conducted during FY 1989 and FY 1990. The project will perform threat/radar response evaluation and analyses leading to multiple GBR system design concepts. Each concept will be evaluated in sufficient detail to establish system effectiveness, technical and programmatic risks, cost estimates, and interface requirements. Two GBR concepts will be selected for a competitive 12-month preliminary design phase.

Technology Understanding

The GBR project has identified four key technical issues critical to the mission success: radar performance, radar discrimination, nuclear effects mitigation, and electronic counter countermeasures (ECCM) capability.

Figure 5.2-4
GBR-X



Three measures of radar performance are tracking accuracy, signal processing speed, and real-time imaging capability. In these areas, a number of hardware developments are required. The solid-state phased array (TDSSPA) project is developing high-power, high-efficiency transceiver modules. Combining these modules into a usable radar requires innovative antenna design. A wideband, wide-scan design has been validated, a test feed system for the subarray fabricated, and measurements obtained which demonstrate the advantages of the technology.

Traffic handling presents the major processing issue. Real-time imaging with an X-band phased array has not yet been demonstrated. The GBR-X experiment will validate signal processor requirements and provide the first data on real-time wide bandwidth imaging.

Accomplishments

During FY 1988, a number of significant studies relating to analyses of discrimination performance, techniques for locating and discriminating targets in chaff clouds, of the ability of the radar to counter enemy electronic countermeasures, and performance in nuclear radiation environments were conducted. These analyses served to validate the design concepts incorporated into GBR-X and to form a basis for developing detailed algorithms and operational procedures.

Future Plans

The discrimination test beds will continue to be used throughout FY 1989 to develop discrimination techniques using real-time data obtained through earlier data collection efforts.

In FY 1989, the results of the imaging studies conducted to address the impact and mitigation capabilities of wideband pulse radar in a nuclear environment will be presented. Predictions of the degree of mitigation of the nuclear environment on system performance and limitations on the system design will be established.

A test will be conducted to determine the effectiveness of the transmitter upgrade. The goal of the upgrade is to develop a pulse capable of penetrating certain ECM capabilities.

In FY 1991, real-time ECCM algorithms will be demonstrated which are designed to mitigate and defeat ECCM environment so that the defense can accomplish its mission. The CONUS readiness review will verify that the hardware and software design of the GBR-X supports multiple-target, real-time, high-throughput discrimination requirements.

Midcourse discrimination algorithms are being developed in a parallel path to GBR-X and will be integrated into the GBR-X design in FY 1989. The GBR-X Dem/Val experiment will validate real-time, multitarget operation, midcourse imaging, and discrimination of test objects as well as PBV observation and tracking.

5.2.4 Command Center/System Operation and Integration Functions

The former BM/C^3 element has been redefined as the Command Center/System Operation and Integration Functions (CC/SOIF). The Command Center is an SDS element emphasizing the need for humans-in-control. The SOIF comprises the hardware and software needed to support information exchange among all SDS elements and to implement human decisions.

Concept and Project Overview

The Command Center element is the SDS human command and control interface and consists of fixed and mobile units and a terrestrial communications network with ground entry points that provide interconnectivity between space and terrestrial components. The Command Center element also supports coordinated offense-defense operations and interfaces with other United States government agencies.

The System Operation and Integration Functions constitute a distributed information processing network needed for the automated execution of a human-selected battle plan. This requires the assured exchange of information between the Command Center and all SDS elements and the data processing required to identify targets, allocate interceptors, execute and assess the defense, and manage resources.

Technology Understanding

There are six critical CC/SOIF technologies: Command Center design, algorithms, software engineering, processor performance, communications, and networking.

A Command Center experiment will be conducted under the Pilot project which supports the design and engineering prototype of the Command Center element. Three activities have been identified: (1) Command Center functions definition, (2) man-machine interface definition, and (3) prototype development. The project will support the generation of hardware and software specifications, the evaluation of alternative concepts of operation-doctrine-procedures, and provide a focus for multi-element integration. The first prototype will be delivered in FY 1990.

The Experimental System project integrates the prototype CC/SOIF subsystems and the NTB to provide simulations and emulations of increasing complexity and fidelity. System level experiments will evaluate hardware/software/human-in-the-loop for a CC/SOIF system driven by threat scenarios. The EV88 experiment uses high fidelity models of sensors, interceptors, and environments to evaluate the Phase I architecture. An SDS development laboratory will be established to permit advanced experiments capable of simulating all phases of strategic defense and architecture variations.

Tracking and discrimination experiments are required to validate the performance of multiple-sensor data fusion to demonstrate our ability to identify hostile objects in a target-rich environment. Figure 5.2-5 depicts a display of simulated booster tracks, showing an increase of tracking validity as stereo tracks become available. Complex simulations are required to prove the effectiveness and adaptability of interceptor-target assignment algorithms, as well as to establish trust in the software that implements these decisions.

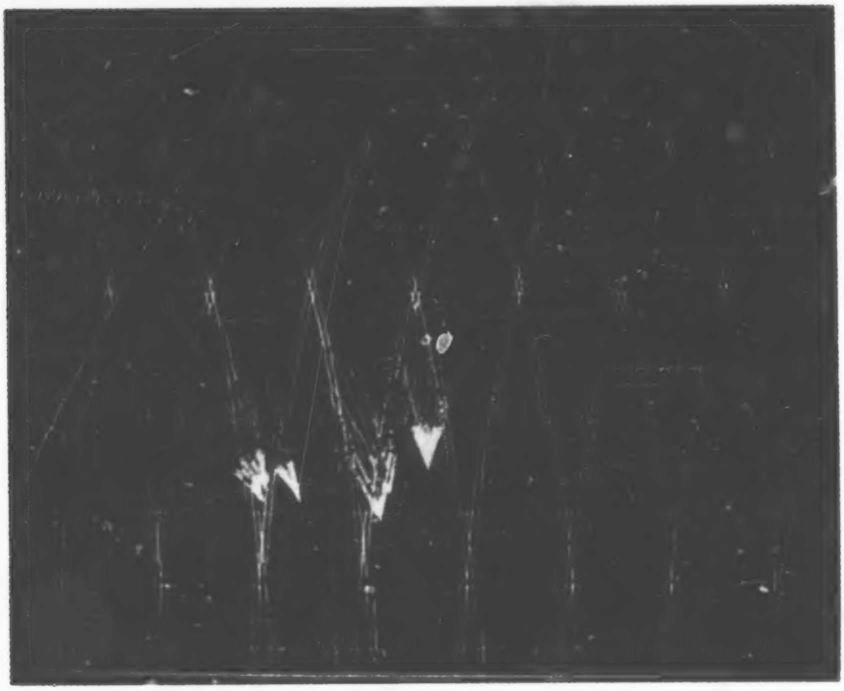
Human-in-control simulations will evaluate assured connectivity under all operating conditions. To validate this assured communications capability, network routing and adaptive resource-control techniques are being tested. The space and ground networks and their interfaces must support both command and control and sensor data transfer. Multiple test beds may be required to verify design capabilities.

Analysis and research are required for near-term development and prototyping of communications technology, devices, and subsystems that are secure, robust, and support the SDS multimode/multimedia mission. This task also includes the development of embedded software and hardware for communications routing, authentication, and security.

Accomplishments

In the past year, several major achievements have confirmed the rapid development and expansion of effort in this element. Highlights include the following:

Figure 5.2-5
JPL Booster Tracks



- A baseline CC/SOIF architecture was identified; the automated decision functions (SOIF) are distributed to interceptor and sensor platforms. Communication support comprises two space-based "carousel" networks (BSTS and SSTS) and a dedicated ground-based fiber optic system.
- Initial requirements for an Experimental Systems program were identified to establish the validity of Experimental Versions as representing essential CC/SOIF technologies. Development of prototype versions has been part of this work.
- The EV88 Levels 0 and 1 demonstrations addressed all six critical technologies with significant results that have been incorporated into the Experimental Systems program. The demonstrations included human-in-control evaluations. Figure 5.2-6 shows the Command Center facility for input to the simulation.

- A software policy was adopted based on the recommendations of the Defense Science Board (DSB). This policy promotes changes in attitudes and practices for software acquisition. Among other features, it emphasizes standardization (Ada language), supportability, risk reduction, security, reuse, and documentation. In all these areas the policy provides separate levels for routine and mission-critical software, and distinguishes between Dem/Val and FSD products.
- Interceptor/target pairing algorithms and multi-object, multisensor tracking algorithms were implemented on parallel architecture computers.
- A processor-to-processor electronic interface between the National Test Facility and the EV88 simulation site was established and is in use. Figure 5.2-7 depicts the Advanced Research Center computer layout that supports the EV88 simulation.

Figure 5.2-6
EV88 Human-in-Control Simulation Station

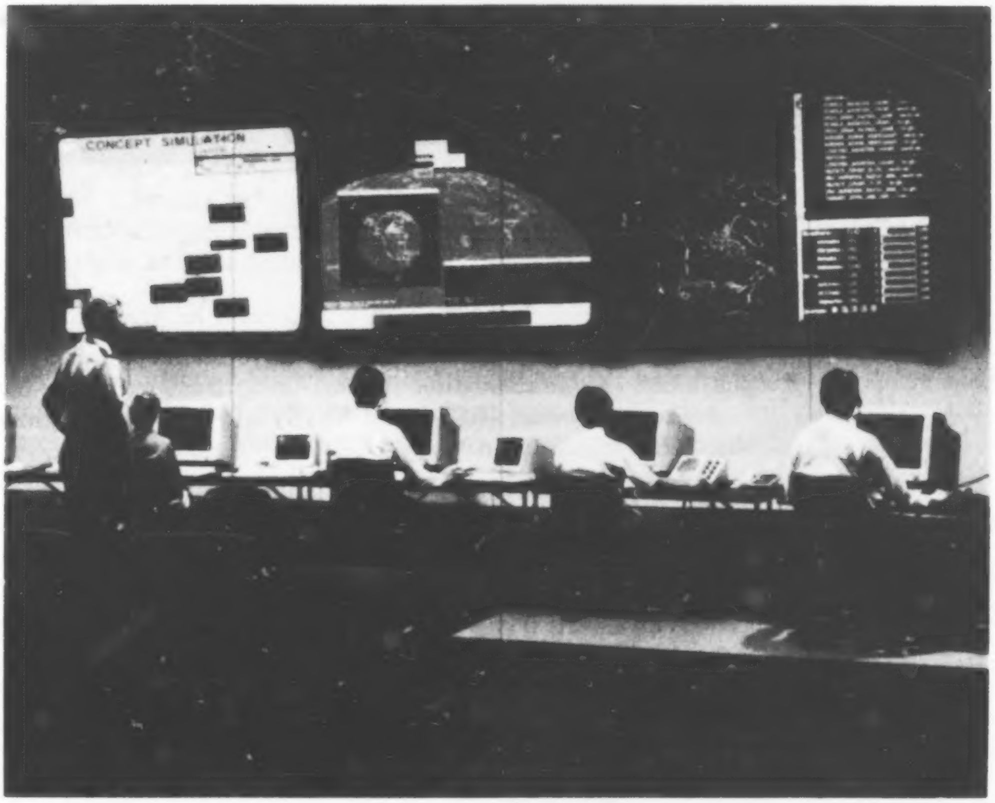
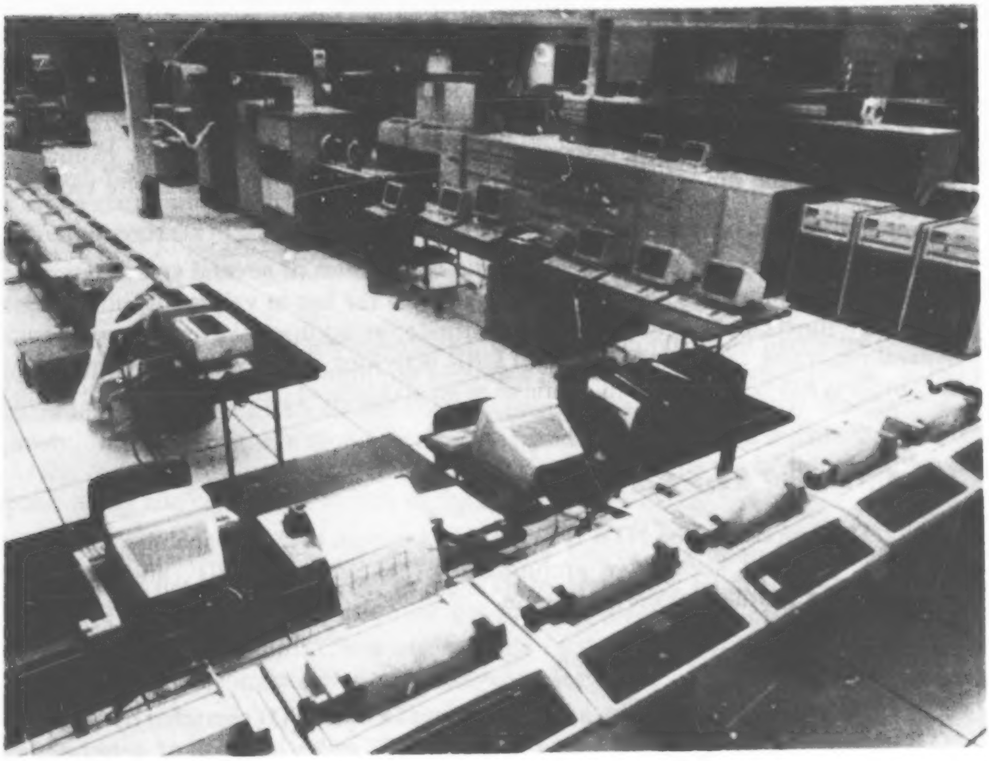


Figure 5.2-7
Advanced Research Support Center for EV88



Future Plans

In the coming year, the CC/SOIF program will continue to evolve using two related but distinct types of new information. One type comes from experiments and planned research. The other draws upon work on other elements that impinge on the command activities. The main items in both are summarized in the following paragraphs.

Development of the Pilot Command Center Experiment. A key thrust of the CC/SOIF program is to conduct a series of experiments to test and demonstrate the command center functions and the human interface. These experiments will resolve concept issues and build the technical foundation for a command center procurement.

Development and Refinement of Sensor Planning Algorithms for the SDS Phase I Design. The current SDS Phase I design requires close coordination of multiple sensors to provide needed coverage of the battle space. This will require the development and evaluation of algorithms to perform the function of sensor planning.

Establishment of an SDS Development Laboratory for the Conduct of Advanced CC/SOIF Simulations. A long-term object of the CC/SOIF experiment program would combine actual software, hardware, and deployed systems (as they become available) in a high fidelity experiment environment for testing the integrated system operation.

Refinement of the Content and Scope of Experimental Activities. The STELLAR Task Force conducted an in-depth review of the CC/SOIF experiment program during the summer of 1988 and recommended the future direction and content for FY 1989 and beyond. In response, the CC/SOIF program has begun planning and budgeting for the initiation of a series of experimental activities that are required to successfully execute the CC/SOIF Dem/Val program.

Utilization of Space Test Data. With the completion of several space experiments (SIE, etc.), real data are now becoming available for use in validating simulations of CC/SOIF functions. This trend will continue, as additional experiments occur in several programs. As part of the STELLAR activities, the feedback of empirical data into models has begun and will continue at an accelerated pace for the entire Dem/Val phase.

5.2.5 National Test Bed

The purpose of the NTB is to provide a comprehensive capability to compare, evaluate, and test alternative architectures; develop CC/SOIF; and provide the simulation for a strategic defense system.

Concept and Project Overview

The NTB is managed by a Joint Program Office (JPO) chartered by SDIO. The NTB consists of the National Test Facility (NTF) and a network of geographically dispersed test facilities. The addition of improved capabilities for the NTB will occur as system requirements evolve. CC/SOIF features, as well as various defense technologies, will be evaluated in a system framework defined by alternative architectures. The definition and acquisition of the NTB capability have been centralized to ensure that a single integrated capability dedicated to the SDS is available to the entire SDI community.

During FY 1988, approximately $35 million was spent in facilities construction and procurement of hardware and software to achieve the desired level of simulation. Additionally, $1.1 million was spent on temporary modifications to the Consolidated Space Operations Center, to include the Special Access Facility and Gaming Center.

Technology Understanding

The critical issues necessary to support informed decisions on the future development and deployment of a strategic defense will be addressed in analyses, research, and simulations at the NTB. The NTB will host the following activities:

- Simulations to test SDS designs
- Validation of the CC/SOIF portions of the SDS

- A standard data base of simulations
- A software center of excellence.

Accomplishments

The STELLAR project defines a framework of experimental activities to address the SDS Phase I system. It focuses the several ongoing experimental activities (e.g., EV88, CCEV) in a more integrated manner centered on the NTF. STELLAR consists of nine experimental activities to resolve eight high-priority issues. Each of these activities consists of a series of experiments, tool developments, and validations.

Future Plans

The NTB, when fully developed, will be a composite of hardware, software, facilities, and personnel at multiple locations providing the above services. SDIO is planning the communications network necessary to interconnect the facilities of the Army, Navy, Air Force, national laboratories, and our allies into a distributed network. At the center of this network will be the NTF, which will be the central coordinating, controlling, and computing facility of the NTB.

Simulations of the integration of the sensor, command and control, and engagement functions will occur in the NTB as part of the STELLAR project. These activities will begin in FY 1990 or FY 1991. Construction of the NTF building commenced in FY 1988. Completion of the facility is scheduled for FY 1990. An NTB integration contractor was competitively selected.

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Section 5.3

Initial Kinetic Energy Projects

5.3 Initial Kinetic Energy Projects

Initial interceptor projects are the space-based interceptor (SBI) and the ground-based interceptor (GBI). The GBI project evolved from the Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS) (as described in last year's report). These projects provide the basic interceptor elements of a flexible layered defense. The SBI was designed to intercept and destroy boosters, post-boost vehicles, and reentry vehicles (RVs) during midcourse. The GBI will destroy RVs in the midcourse layers. This combination of space- and ground-based interceptors can be changed to respond to evolving threat characteristics and attack strategies. However, an alternative concept, called "Brilliant Pebbles," can potentially do the same job at reduced cost and complexity. Brilliant Pebbles is discussed later in this section.

5.3.1 Space-Based Interceptor

The SBI will be a chemical-powered, kinetic energy ballistic missile intercept subsystem designed to engage enemy targets in the boost, post-boost, and early midcourse portions of their trajectories. The current design utilizes a carrier vehicle (CV) constellation with each CV carrying a quantity of interceptors. SBI is the first tier of the planned Phase I system and will be linked to the BSTS and SSTS elements via communications.

Concept and Project Overview

The SBI element of the SDS will engage the threat in the boost, post-boost, and midcourse layers. A percentage of the SBI satellites would normally be in range of Soviet ICBMs in the boost, post-boost, and midcourse layers. This percentage can be increased during a crisis. Soviet defense suppression efforts, which rely on antisatellite (ASAT) attacks on the SBI CVs to open a hole for their ICBM launch, must take into account the criticality of the timing in order to destroy SBI satellites which are distant from the Soviet Union. They must also account for the "self-annealing" characteristic of satellite coverage as new satellites enter the engagement area.

Changes in the SBI concept from 1988 to 1989 are summarized in Figure 5.3-1. These changes reflect successful research to improve performance. Because of major advances in the projectile portion of the SBI, the weight was reduced, allowing each interceptor to operate at increased velocity and range, thus reducing the satellite constellation. The constellation size was further reduced with the development of selective targeting algorithms.

In addition to the design changes, employment tactics have improved. The improvements in design and tactics will result in the destruction of additional RVs for equal numbers of interceptors. This improved effectiveness has been utilized to maintain the SBI role in meeting operational requirements while reducing constellation size. The increased ratio of reentry vehicles destroyed for each on-station interceptor reflects improved architecture efficiency. As with previous architectures, the majority

Figure 5.3-1
Changes in SBI Concept

	Previous Concept	Current Concept
Carrier Vehicle		
Number	–	-50%
Principal Survivability Measures	–	—
Boost Commit Time	–	-29%
PBV Commit	Booster Burnout	Early
Orbit Flexibility	None	Yes
Sensor	Multicolor Fire Control Sensor	Not Required
Interceptor		
Axial Velocity	–	+25%
Flyout Time	–	+100%
Interceptors per CV	–	No Change

of reentry vehicles destroyed by the SBI element of the SDS Phase I occurs in boost and post-boost engagements, with a decreasing percentage occurring in midcourse.

SDIO studies have identified the CV as driving the cost for the SBI. The initial projections for interceptor performance required the incorporation of a very capable and expensive CV fire control sensor. This sensor subsystem was required to track targets accurately and relay target updates to the interceptors in flight. Reviews of the designs for BSTS and SSTS satellites and experiments, such as Delta 181, provided the confidence that the sensor capability of these satellites, coupled with better battle management software, could handle the required fire control functions. Therefore, dedicated fire control subsystems on the CV were not required. Removal of these sensors reduced CV cost by resulting in significant simplifications in the design requirements for almost all remaining CV components and functions, including power, attitude control, thermal control, and structures.

Advanced Concepts: Singlets, Brilliant Pebbles

Specialized and highly advanced technology research projects, such as "singlets" and Brilliant Pebbles, offer ways to further improve SBI performance.

SDIO studies have found that maximum system flexibility, and growth potential, could be achieved by minimizing external interfaces. This requires building as much capability into the interceptor as technology allows. The interceptor could be outfitted with a simple "life jacket" to provide power, environmental control, navigation, and attitude control. This concept, called singlets, could be implemented without a major cost increase. Incorporating this feature would provide the capability to add interceptors to an existing architecture, either one at a time or in optimized groupings, to improve performance.

The concept of a singlet is embodied in a concept called Brilliant Pebbles. Given a release command, the interceptor uses its own sensors to acquire a target and engage it without external tracking data or other assistance.

The major features of the Brilliant Pebbles concept are its size, cost, operability, and survivability. The Brilliant Pebbles interceptor is small and light. Thus the interceptor requires minimal space-launch capability to be deployed.

The interceptor has a low cost because it is derived from pervasive use of miniaturized commercial and military "off-the-shelf" high technologies, including a set of miniaturized high-resolution/wide-field-of-view video imaging systems, a super computer with Cray-1 performance operating off high-energy-density batteries, an imaging radar/communications system, and a high-mass monopropellant propulsion system.

The interceptor's passive features—small size, low cost, and dispersal ability as singlets—are jam resistant, provide low-detection cross section, enable the interceptor to be supplemented by decoys, and provide low value per individual target. These features are supplemented by a full nuclear survivability suite and extensive maneuver capability for breaking track, evasion, and antisimulation in conjunction with constellation decoys.

Several design aspects of the Brilliant Pebbles concept are worth noting. The navigation system is based on an already-demonstrated, real-time stellar navigation module and standard miniature angular-rate-sensing and linear accelerometers, backed by a high-precision clock. Whether ground launched or space deployed, each interceptor always has highly accurate knowledge of its heading and location. Its restartable propulsion system can be used to maintain any specified trajectory. Even if flown at low altitudes, station-keeping fuel requirements permit the interceptor to fly such orbits for a decade before using an unacceptable fraction or more of its on-board propellant.

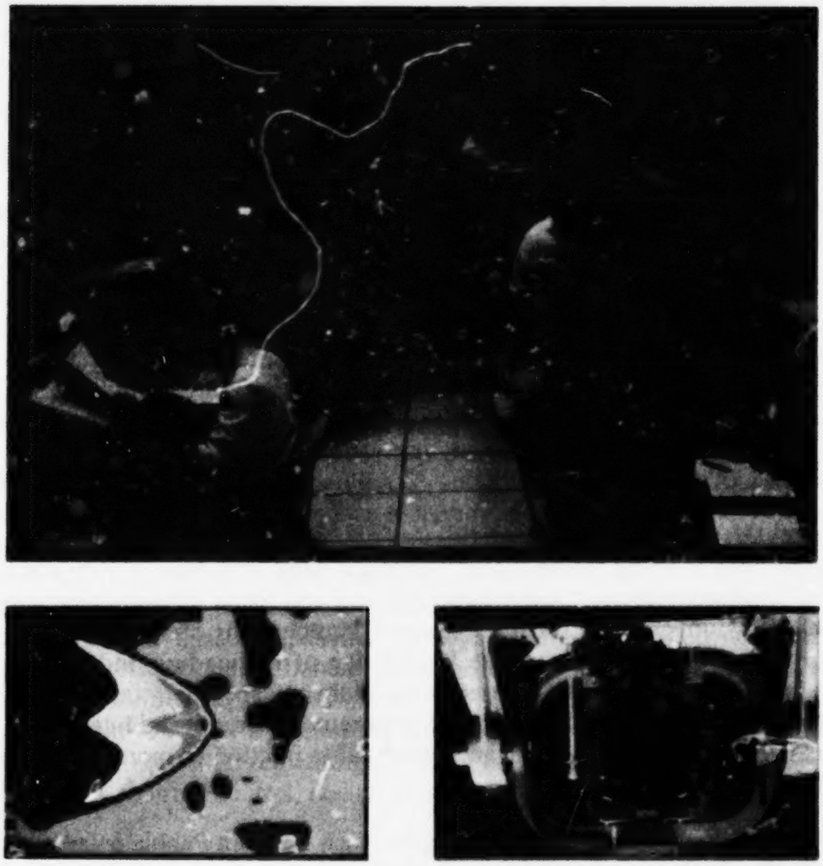
If deployed as a space-based interceptor, each Brilliant Pebble is launched with a "life jacket" which provides solar-derived electric power through a rechargeable battery as well as thermal environment control. The jacket is discarded after the interceptor has been ordered into the battle.

Accomplishments

To accelerate the validation of SBI and GBI advanced technology research, SDIO has established an integrated kinetic energy technology program. The resulting hardware will be tested at contractor facilities as well as at independent government facilities such as the newly operational Kinetic Hardware-in-the-Loop (KHIL) Facility at Eglin AFB (Figure 5.3-2) and the Kinetic Hover Interceptor Test (KHIT) Facility at Edwards AFB. The National Test Bed will be coupled to these national facilities to support multi-element testing.

Figure 5.3-2
KHIL Facility

Real-Time Computer Suite



In-Band Scene Projection

Flight Motion Simulator

In 1988, components contemplated for SBI completed this first cycle of integration and functional validation. Several of these technology pathfinders provided components which will enter various phases of laboratory testing in 1989, enabling integrated projectiles to be assembled. The major components of interceptors that completed this cycle include seekers, avionics, trackers, communication links, inertial measuring units, control propulsion units, and some weapon satellite support equipment. Size and cost reduction of the contemplated SBIs has been impressive. A 3-kilogram end-game projectile is now realistic.

Specific examples of critical SBI components that completed the testing in 1988 include a 64 x 64 pixel mercury cadmium telluride seeker array (Figure 5.3-3). Producibility improvements increased the yield of this array. A quantity production is being planned with other agencies to demonstrate cost-controlled production. The first application of very large-scale integration (VLSI) military standard computers for the SDI Program was completed by three independent contractors. Throughputs for million instructions per second (MIPS) commands have been achieved for seeker signal processors which now weigh one-half pound, as opposed to 120 pounds a few years ago (Figure 5.3-4). These processors have been through hardware-in-the-loop testing by contractors and the government. Attitude stabilization performance in small inertial units has been improved by two orders of magnitude. These improvements will result in an SBI inertial measurement unit weighing about one-tenth of a pound with a projected cost in production of less than $5,000 (IMU technology is shown in Figure 4-2).

Figure 5.3-3
CCD Array

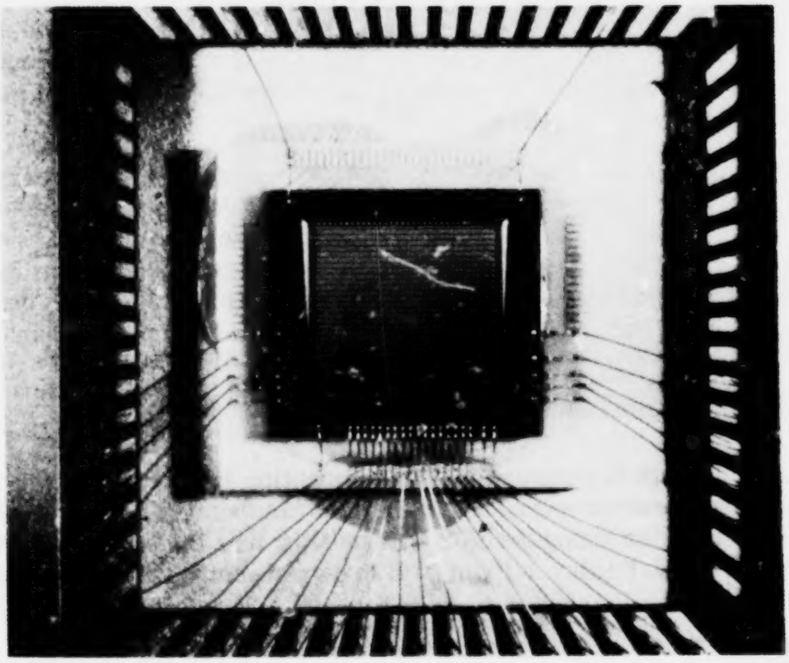
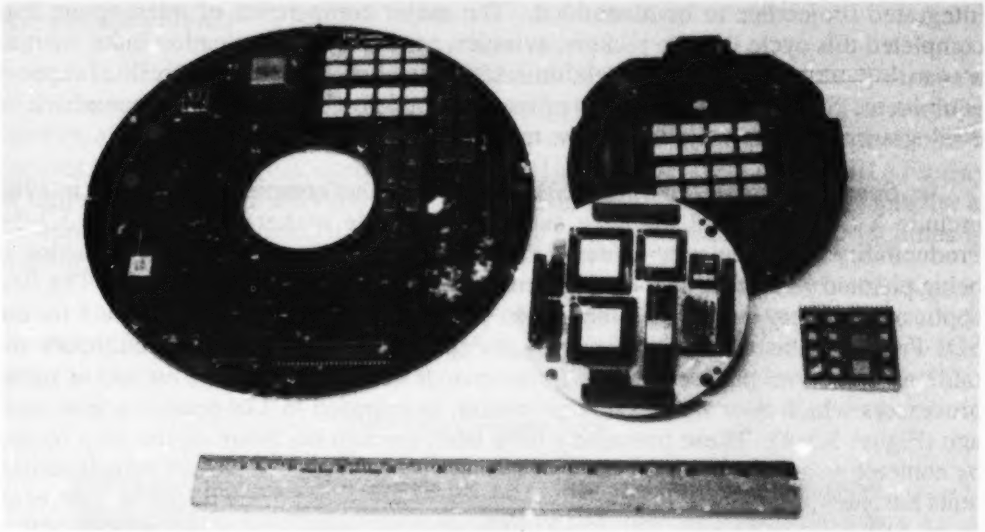


Figure 5.3-4
High-Speed, Miniature Processors



In a similar fashion, gallium arsenide hardware for communications and robust tracking algorithms that depend on commercial imaging technologies have been demonstrated and incorporated into the program (see Figure 5.3-5).

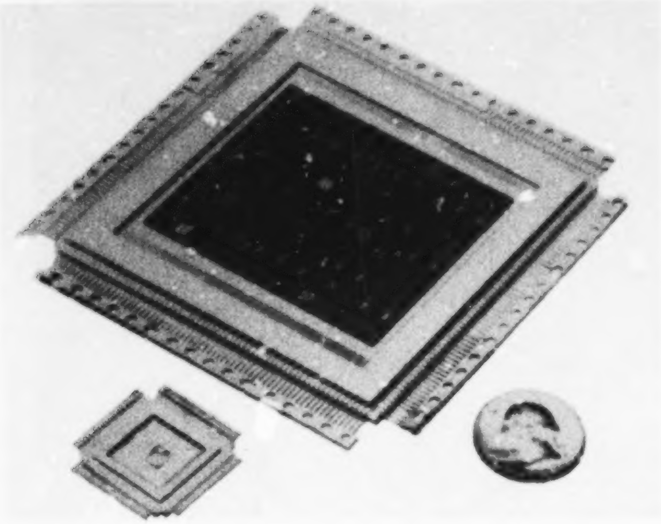
Controls and axial propulsion units were also tested over the past year. A second-stage multistart engine has more impulse and a better mass fraction than any other space-storable engine. An integrated test of SBI attitude control and divert engines was successfully run at contractor and government laboratories in July 1988 (see Figure 5.3-6).

SBI designs are modular in construction. The modular design is expected to drastically reduce the amount of testing time to space qualify each satellite. Product improvement, satellite retrieval, and on-orbit repair and resupply are also supported by modular design. Hardware-in-the-loop, hover test, and digital emulation facilities have been developed to reduce dependence on space testing. Figure 5.3-7 shows the kinetic hover interceptor, the first flight test of SBI stability and control algorithms, which occurred in October 1988 at the KHIT Facility at Edwards AFB.

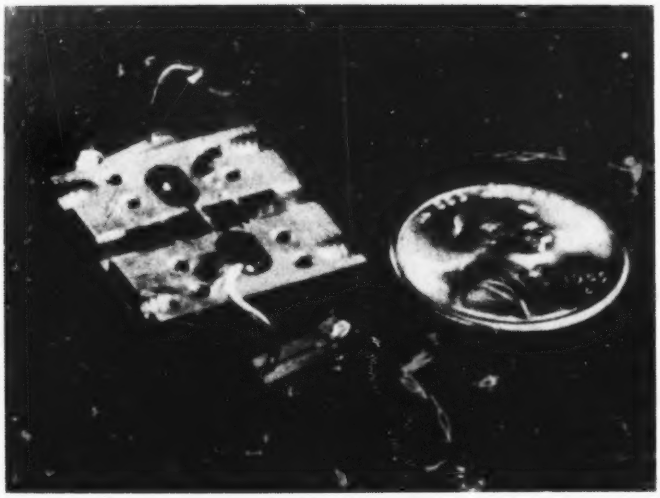
Future Plans

During concept demonstration, the competition between concepts will be maintained to accelerate progress. Data from the competition will be used in the available simulations, including the SDS National Test Bed, the Edwards AFB KHIT Facility, and the KHIL Facility at Eglin AFB to do real-time multi-element tests. As

Figure 5.3-5
SBI Agile Communications



A mass memory integrated circuit developed using wafer scale integration (WSI) processes (center). Lower level of integration available in today's VHSIC technology (bottom left).



Millimeter-wave low noise amplifier using monolithic microwave integrated circuit (MMIC) technology.

SBI proceeds into FSD, two contracts will be issued: one for the development of the interceptor and one for the CV. These efforts will further refine the designs to prepare for a production decision.

Figure 5.3-6
Divert/ACS Propulsion Technology

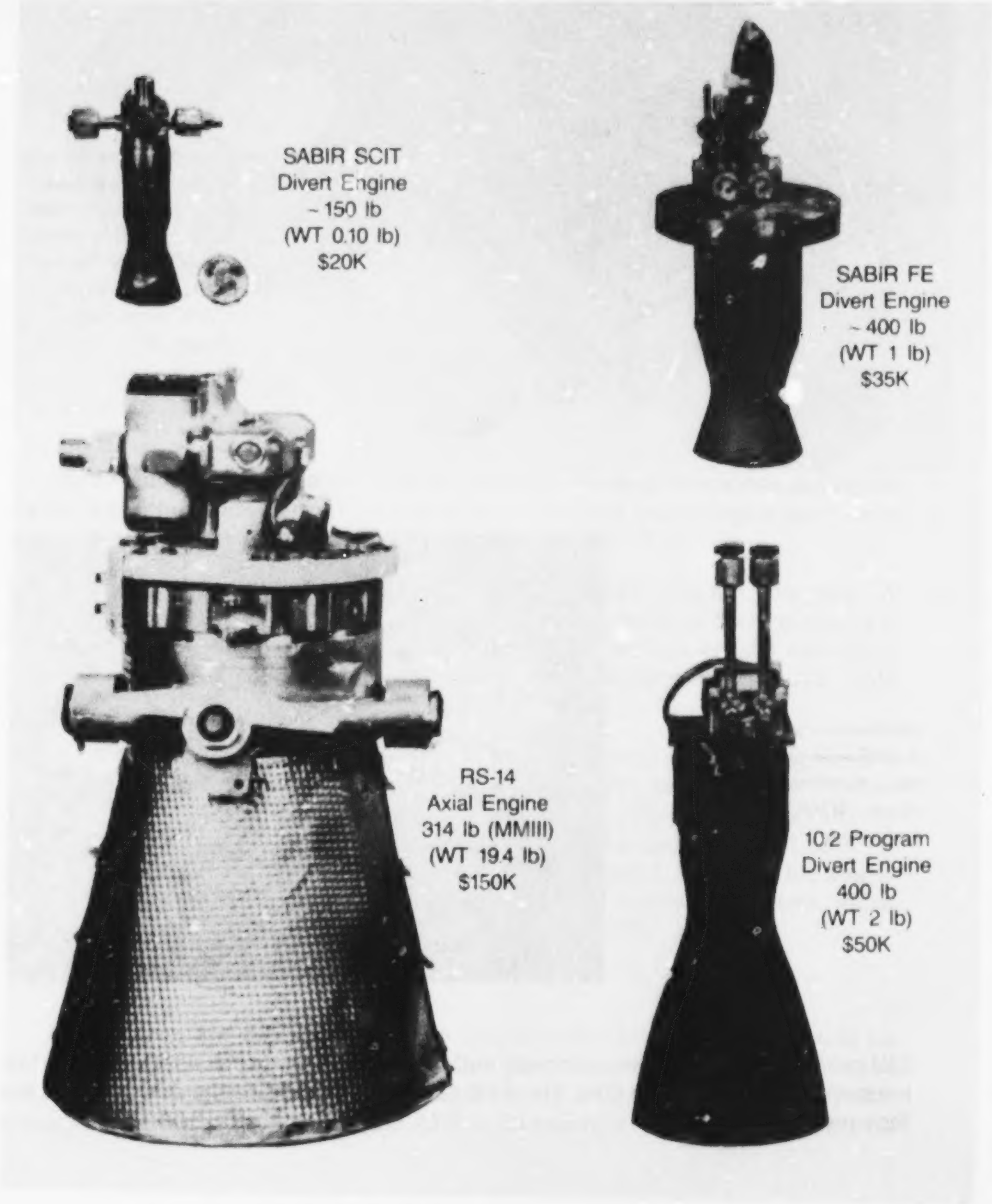

SABIR SCIT
Divert Engine
~150 lb
(WT 0.10 lb)
$20K
SABIR FE
Divert Engine
~400 lb
(WT 1 lb)
$35K
RS-14
Axial Engine
314 lb (MMIII)
(WT 19.4 lb)
$150K
10.2 Program
Divert Engine
400 lb
(WT 2 lb)
$50K

Figure 5.3-7
SBI Hover Test

The SBI testing program will be tailored to the phases of the acquisition process. The current SBI concept requires testing both interceptors and CVs. The primary new function of the CV is to launch the interceptors. The CVs are very similar to other satellites in their housekeeping functions. For this reason these satellites should not require testing in space during Dem/Val. However, the interceptor will require testing in space during Dem/Val. The seeker will require testing of its capability to acquire and intercept targets. The data will validate hardware-in-the-loop ground tests, hover tests, and digital emulations used to investigate the SBI performance boundaries. The necessary space testing will be accomplished through flight tests at either Kwajalein or White Sands Missile Range. Originally planned for late FY 1989, the ballistic tests have been delayed to take advantage of new, lighter-weight, lower-cost technology.

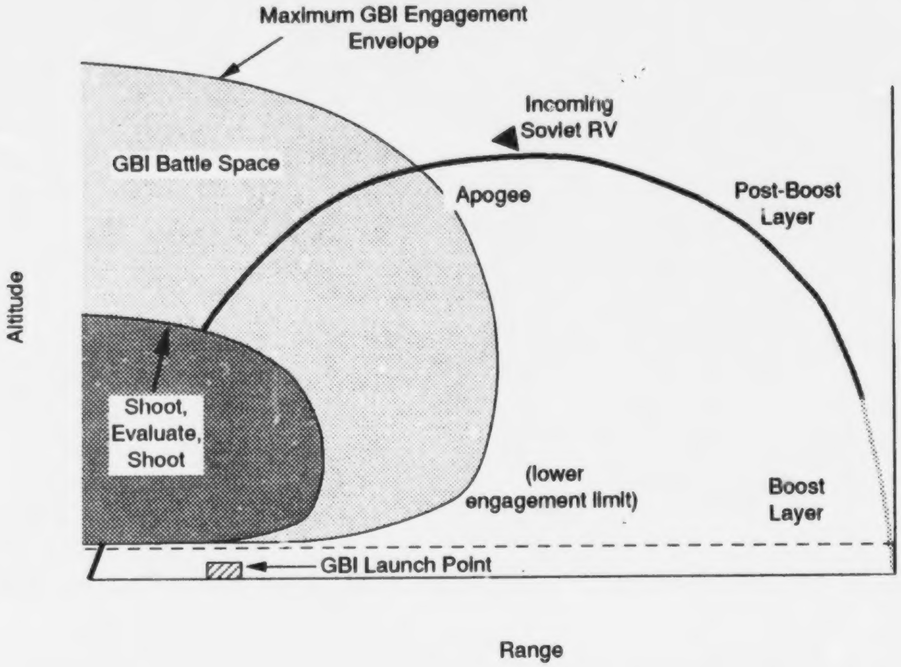
5.3.2 Ground-Based (Exoatmospheric) Interceptor

ERIS, the Exoatmospheric Reentry Vehicle Interceptor Subsystem referred to in last year's report, is in the Dem/Val portion of the GBI project.

Concept and Project Overview

The GBI element of the SDS would engage the Soviet ballistic missile threat from near apogee to the late midcourse portion of the trajectory. The GBI engagement envelope is shown in Figure 5.3-8.

Figure 5.3-8
GBI Engagement Envelope


Maximum GBI Engagement Envelope
Incoming Soviet RV
GBI Battle Space
Apogee
Post-Boost Layer
Altitude
Shoot, Evaluate, Shoot
(lower engagement limit)
Boost Layer
GBI Launch Point
Range

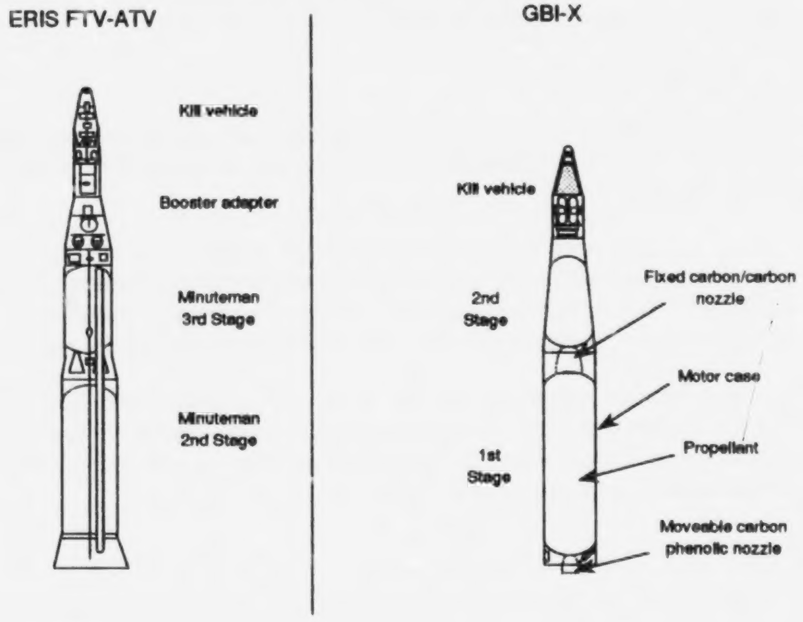
This ground-based missile will launch a kinetic kill vehicle from fixed sites in the continental United States. The midcourse sensors will acquire, track, and pass target information to the ground-based Command Center element. The ground battle management segments will discriminate, assign interceptors to targets, provide trajectory and launch data to the interceptor, and communicate target state vector updates to the interceptor in flight. The interceptor will have some on-board discrimination capability to relieve data rates and processing requirements on board the midcourse sensor.

Technology Understanding

The GBI development program has two parts: (1) demonstration and validation of the concept and technologies and (2) development of advanced exoatmospheric interceptor technology. Demonstration and validation are further divided into ERIS Functional Technology Validation (FTV) and Advanced Technology Validation (ATV).

The FTV will demonstrate and validate low life-cycle cost GBI concepts and associated technologies for an interceptor designed to utilize off-the-shelf technology for cost savings. Advanced technologies are being developed which increase performance beyond FTV levels. The ATV will validate these advanced technologies, including those identified by GBI, to increase the interceptor capabilities and permit greater flexibility in interceptor design. The ATV series also addresses additional stressing threats and nuclear background effects. Technologies validated in the series include a two-color staring LWIR seeker, LEAP seekers, cooled optics, an advanced IMU, visible and ultraviolet (UV) focal planes, discrimination enhancing sweeper, and improved avionics. Figure 5.3-9 compares the ERIS FTV-ATV with the subsequent FSD interceptor (GBI-X).

Figure 5.3-9
ERIS FTV-ATV vs. GBI-X


ERIS FTV-ATV
Kill vehicle
Booster adapter
Minuteman 3rd Stage
Minuteman 2nd Stage
GBI-X
Kill vehicle
2nd Stage
Fixed carbon/carbon nozzle
Motor case
1st Stage
Propellant
Moveable carbon phenolic nozzle

---

* Not shown to scale.

The vehicle tested in FSD and built in production will be the ground-based interceptor. There will be approximately 22 prototype flight vehicles built and tested with hardened, operational components.

Key GBI avionics components are the data processor and the IMU. A primary goal is to increase the processing throughput and harden the electronics while keeping the weight down. This will be accomplished using very high speed integrated circuits (VHSIC).

The FTV flight tests will demonstrate and validate technologies applicable to the midcourse problem. The ATV test series will flight test advanced components along with improved target selection software.

The principal seeker advanced development goal is to provide a capability to find the target in an increasingly stressing threat environment. The seeker will be cooled in flights and enable the interceptor to be dormant and battle ready. Cooled optics and a two-dimensional FPA, which can be integrated with the current seeker, are being developed. This staring seeker will be tested on an ATV flight test.

A major effort is under way to enhance interceptor propulsion by developing lateral thrusters that will provide sufficient thrust over multiple increments to divert the vehicle to intercept the target. Also, these thrusters will be used as a means to implement the forward reaction attitude control system concept for in-flight nose end steering and thus reduce the propulsion system cost. There are also projects to develop low-cost first- and second-stage boosters.

Accomplishments

A critical design review of the FTV and the air vehicle structure was completed in July 1988. This will allow significant system-level hardware development to proceed on schedule.

Two seeker assemblies were delivered and seeker flight testing was completed. Flight version avionic packages were delivered and contractor subsystem HWIL testing was initiated. Nose fairing and kill vehicle separation tests were conducted. Electromagnetic testing was conducted and interceptor sensor model test completed.

The technical requirements for ATV and initial flight test planning were completed. Development efforts are continuing for components for the ATV tests. The government also commenced independent testing of the advanced technology components intended to support the FSD.

Future Plans

Kill vehicle model testing will be conducted and flight software will be certified. Hardware/software integration and ground tests will be conducted, leading to the ATV flights. The advanced seeker components will be incorporated into the first ATV flight. This will initiate a series of flights incorporating candidate FSD components on a proven test missile.

Section 5.4

Theater Defense

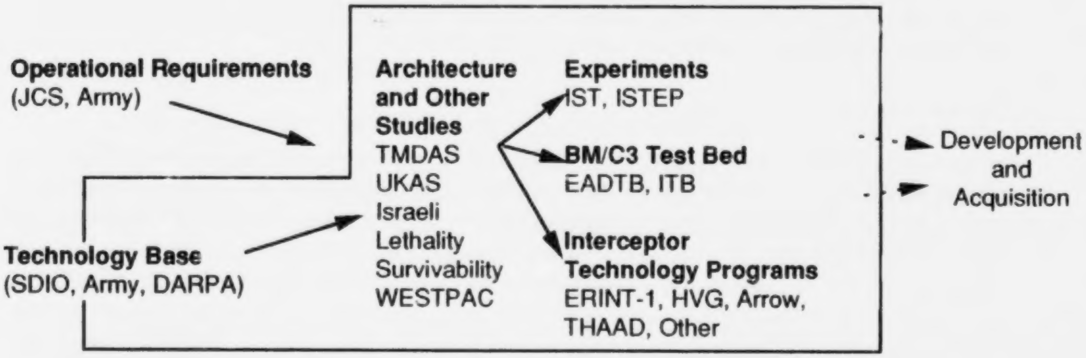
5.4 Theater Defense

This section discusses theater defense concepts, architecture studies, the theater test bed, and accomplishments in and future plans for theater defense.

5.4.1 Concept and Project Overview

The theater defense program combines architecture studies, test bed development, and technology research to form the basis for decisions to develop and deploy defenses against missile threats to allies and U.S. forces abroad. The theater defense technology development concept is shown in Figure 5.4-1.

Figure 5.4-1
Theater Defense Technology Development Concept


Operational Requirements
(JCS, Army)
Technology Base
(SDIO, Army, DARPA)
Architecture and Other Studies
TMDAS
UKAS
Israeli
Lethality
Survivability
WESTPAC
Experiments
IST, ISTEP
BM/C3 Test Bed
EADTB, ITB
Interceptor Technology Programs
ERINT-1, HVG, Arrow, THAAD, Other
Development and Acquisition

5.4.2 Architecture Studies

The Theater Defense Directorate has pursued a series of architecture studies, each specifically tailored to a region of interest and threat. These studies have resulted in preferred architectural concepts and focused efforts on resolving critical technical issues. The bilateral U.S.-United Kingdom Architecture Study (UKAS) provided a perspective of the European threat, while the multinational contractor consortia involved in the Theater Missile Defense Architecture Studies (TMDAS) focused on the near-term SRBM threat to the Central Region of NATO. The bilateral U.S.-Israeli Architecture Study examined the unique threat and environment present in the Middle East, while the recently initiated Western Pacific (WESTPAC) Architecture Study will investigate a new largely maritime region of interest that contains numerous critical C^3 and strategic assets.

5.4.3 Theater Test Bed

The development of theater missile defense architectures will be based on careful analyses of alternatives and their associated cost-benefit ratios. These analyses will benefit from use of a theater or extended air defense BM/C^3 test bed for evaluating effects of changes in technology on architecture design and doctrinal employment. Our allies in Europe and Israel are participating in cooperative test bed programs. The NATO-oriented Extended Air Defense Test Bed (EADTB) will create a simulation-based developmental test and evaluation capability to analyze potential TMD system, component, and related research efforts. The Israeli test bed will be capable of simulating theater defense in the Middle East. Each will be designed to be able to interface with the SDIO National Test Bed through the Army SDC EADTB node in Huntsville, Alabama.

5.4.4 Key Technical Activities

Key technical activities involve identification of the most promising sensor, CC/SOIF, and interceptor approaches to conduct theater defense. Specific discussion of the various technical activities appears below.

Invite, Show, and Test

The Invite, Show, and Test (IS&T) objectives are to (a) solicit mature U.S. and allied technologies applicable to active TMD technology and programs; (b) test and evaluate these existing systems, subsystems, and components; and (c) recommend systems and subsystems for an interim TMD capability. Eight IS&T contracts were awarded in FY 1988 that will provide information with regard to missile active guidance, active and passive target location (sensors), and missile destruction mechanisms. Actual experiments will be conducted in the spring of 1989 to gather and evaluate these concepts.

Extended Range Interceptor Technology

The objective of Extended Range Interceptor technology (ERINT-1) is to develop and demonstrate a pre-prototype missile and launch control system for TMD. Building on the Flexible Lightweight Agile Guided Experiment (FLAGE) technology the program will then provide a missile with hardware elements that are directly traceable to a deployable missile design (e.g., attitude control motors, rocket motor, guidance processor unit, inertial measurement unit, etc.). Additionally, the ERINT-1 flight test program will include a demonstration of the missile capability against an air-breathing target. ERINT-1 should be compatible with and complement current air defense systems such as the Patriot. This missile system adjunct will be capable of performing high speed hit-to-kill intercepts of multiple maneuvering tactical missiles while maintaining a significant keep-out altitude.

Tactical High-Altitude Area Defense

The objective of the tactical high-altitude area defense (THAAD) effort is to define an overlay active missile defense for use in a mid- or far-term architecture by maximizing the application of results of technical experimentation, flight tests, and other experiments such as HEDI/KITE and Arrow programs. This program will begin with concept definition study and lead to a decision to proceed to a demonstration and validation phase.

Arrow

A Preliminary Design Review (PDR) and Critical Design Review (CDR) will be conducted during this phase. Phase III will consist of hardware fabrication and subsystem assembly. Laboratory and ground tests will be conducted to flight qualify the test missile. Software will be developed and propulsion and control tests will be conducted. Four flight tests will be conducted during Phase IV. Three of these tests will use the Arrow missile, a surrogate threat, a pseudo/test fire control center, and instrumentation ground radars.

Supporting Technologies

The objective of the survivability and vulnerability effort is to analyze proposed TMD systems; determine survivability issues and system survivability requirements; develop survivability technology projects and rationale to resolve the issues; and develop operational survivability concept requirements. Technology development projects which support TMD development schedule milestones and have the potential to satisfy operational survivability requirements will be identified.

Foreign technologies contribute to the technology base as well. For example, current efforts funded are hypervelocity gun research with Royal Armaments/Research and Development Establishment, United Kingdom, and Soreq Nuclear Research Center, Israel; a cooperative hypervelocity gun program with the Netherlands; and a radar seeker with Contraves, Italy.

5.4.5 Accomplishments

Previous work, such as research conducted by the United Kingdom, has provided a basis for accomplishments in FY 1989. The U.K.-U.S. architecture analysis scope-of-work was modified in May 1988 to assess the impact of the post-INF Treaty threat on previously defined architectures with a view to modifying them as necessary.

Theater Missile Defense Architecture Studies

The Phase IIA effort of the TMD architecture studies, which focused on the European Central Region SRBM threat, has been completed. It accomplished a detailed concept definition for the selected architecture to include system and subsystem requirements and specifications, identification of interface requirements, requirements balancing among system/subsystem elements, and identification of detailed battle management, C^3 and support requirements. Additional products from this phase were deployment plan, operational deployment concept, and life-cycle cost estimates. The Phase IIA effort was designed against the near-term pre-INF threat. It developed the basis for Phase IIB which will add analyses of post-INF threat, architectural cost analyses, and the definition of technology experiments.

A new series of cooperative programs has been initiated in accordance with the FY 1988 Congressional directive to conserve funds by establishing cooperative active defense programs with U.S. allies. These programs are described further in Appendix B. The SDIO initiated a study in FY 1988 to define possible links between theater and strategic defense architectures in terms of sensor capabilities and active defense system designs.

Western Pacific (WESTPAC) Architecture Study

This concept development study was initiated to evaluate the threat to Japan and associated maritime regions and to derive candidate architectures for the active missile defense of the Western Pacific and associated sea lines of communication (SLOC). The effort uses two multinational contractor teams to execute the SDIO-directed study effort.

ERINT

The attitude control motor technology successfully completed the demonstration and validation tests resulting in a small lightweight control motor to provide control necessary to perform hit-to-kill intercepts. The small size of the attitude control motor is illustrated in Figure 5.4-2. Additionally, the guidance processing unit advances have resulted in significant volume reduction while increasing the memory by a factor of 2.5. Advances in the ERINT-1 guidance processor unit, as compared with the earlier FLAGE, are shown in Figure 5.4-3.

5.4.6 Future Plans

The theater defense program will concentrate on exploiting the information developed during the architecture studies to formulate concept validation and risk reduction experiments. Additionally, increased emphasis on a system engineering approach to develop preferred architectural concepts will focus technology efforts in order to produce high payoff opportunities for TMD. Further, specific experiments will proceed as follows: (1) completion of Arrow design, development, and integration in preparation for a flight test program; (2) first ERINT-1 flight tests against ballistic missiles and air-breathing targets; (3) development of cooperative programs with our allies to provide a prototype artificial intelligence discrimination framework; (4) advances in hypervelocity gun technologies; and (5) a completed extended air defense test bed node. Finally, the master architecture analyses will be completed with the conclusion of the WESTPAC study.

Figure 5.4-2
ERINT Attitude Control Motor

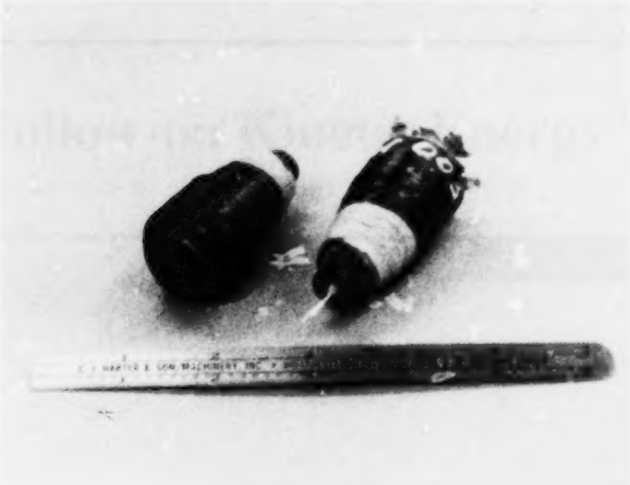
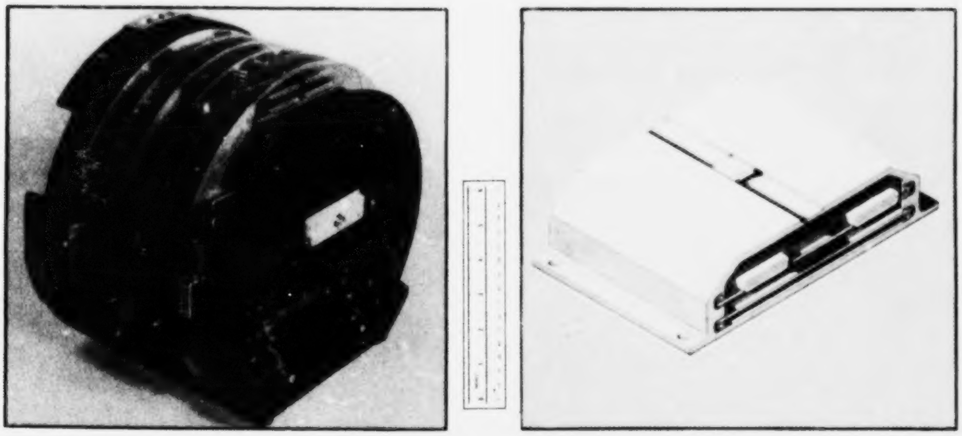


Figure 5.4-3
Guidance Processor Unit Technology



FLAGE
Technology ERA 1983-87

Weight	5.7 kg (12.6 lb)
Volume	0.005 m^3 (300 in^3)
Memory	108K bytes
Cost	$100K

ERINT-1
Technology ERA 1988

Weight	2.3 kg (5 lb)
Volume	0.001 m^3 (75 in^3)
Memory	272K bytes
Cost	$80K Flight Test $16K Operational

Section 5.5

Follow-on Kinetic Energy Projects

5.5 Follow-on Kinetic Energy Projects

This section describes follow-on kinetic energy projects, specifically the High Endoatmospheric Defense Interceptor (HEDI) and the hypervelocity gun (HVG), their accomplishments, and future plans.

5.5.1 High Endoatmospheric Defense Interceptor

This section describes HEDI, its technology issues, accomplishments, and future plans.

Concept and Project Overview

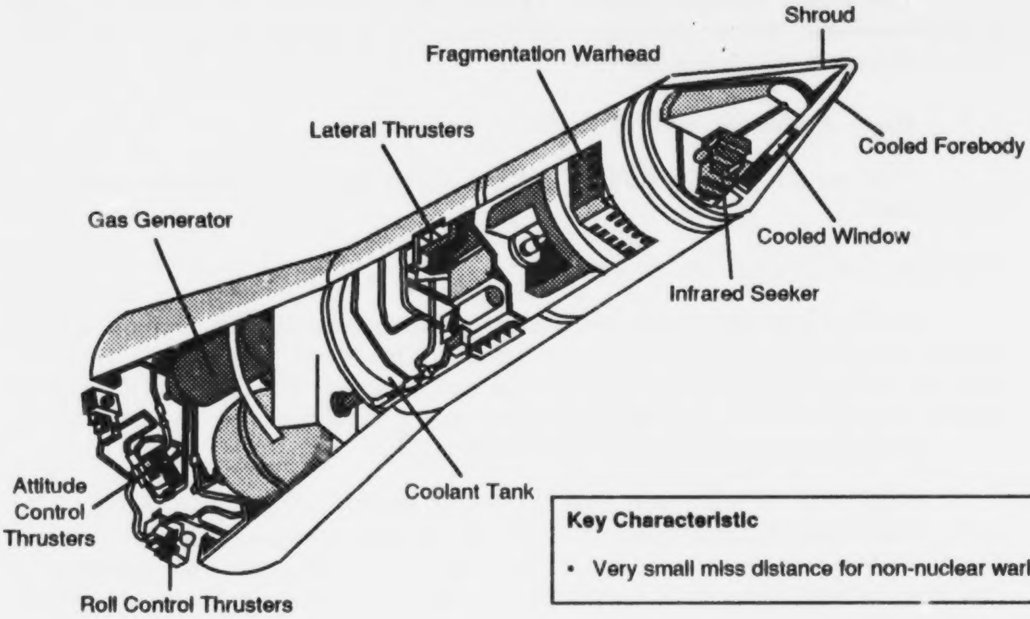
HEDI is a ground-based, hypervelocity, high acceleration interceptor that can engage ballistic RVs in the upper atmosphere. This battlespace enables HEDI to intercept ICBM/SLBM RVs that penetrate the midcourse defense layer. HEDI is able to discern the effects of the upper atmosphere on varying threat objects to discriminate real RVs. The HEDI concept is illustrated in Figure 5.5-1.

HEDI will be integrated with midcourse sensors using the CC/SOIF. The midcourse sensors and associated CC/SOIF will be used to provide RV detection and discrimination, determine the desired RV intercept point, select the appropriate trajectory for engaging each RV, and issue a launch command to the interceptor. HEDI is a fire-and-forget missile which flies to an acquisition point using inertial guidance; it accepts in-flight updates of RV position, if available. A few seconds prior to intercept, the interceptor separates from the booster. After separation, the interceptor acquires the RV with its scanning MWIR seeker and homes to the RV. A laser range finder can be used to detonate a non-nuclear fragmenting interceptor in close proximity to the RV.

HEDI is the most mature interceptor currently in the evolving strategic defense system follow-on architecture. Moreover, because of its maturity and utility, HEDI continues to be a candidate element for a Limited Protection System (LPS). Because of its potentially high utility to an LPS, the technical and programmatic objectives for the HEDI drive parallel experimentation and testing at the same pace as elements already identified in Phase I.

The HEDI project is being realized through several technology definition and experimentation stages. The first effort is to define the key technologies and to demonstrate their respective functional applicability to the HEDI mission. This stage, named the Kinetic Energy Kill Vehicle Integrated Technology Experiment (KITE), is specifically designed to resolve key technical issues and to validate the functional technologies. To this end, several KITE flight tests will be conducted between FY 1989-91. As the technologies become more clearly defined, the baseline design for the operational HEDI will be refined.

Figure 5.5-1
HEDI Concept


Shroud
Fragmentation Warhead
Lateral Thrusters
Cooled Forebody
Gas Generator
Cooled Window
Infrared Seeker
Attitude Control Thrusters
Coolant Tank
Roll Control Thrusters

Key Characteristic

- Very small miss distance for non-nuclear warhead

Functions

- Performs a critical high endoatmospheric role in layered defense
- Accepts both ground-based and midcourse sensor commit
- Acquires, homes on, and destroys an RV with a non-nuclear kill warhead
- Uses endoatmospheric discrimination to a great advantage
- HEDI/Midcourse makes penetration aid threat very costly

As the HEDI project has progressed, a better understanding of the technologies has evolved, leading to more effective baseline performance capabilities for the operational interceptor. The original project required a second major experimental step, the functional test vehicle to resolve those remaining technical issues. However, early successes in a variety of ground experiments and wind tunnel tests permit the acceleration of the project from the experimentation and testing stage through a single experimental pre-prototype flight test into a full-scale development stage when so required. By no longer requiring the costly functional technology validation tests, a savings of $350 to $400 million will be realized in the total HEDI project.

Technology Understanding

Seven HEDI critical technology issues are the result of requirements for hypervelocity flight, maneuverability, and non-nuclear kill in the highly stressing natural and nuclear-altered atmosphere. These technology issues include the following:

- Window and thermo-structural integrity. The goal is to demonstrate that the interceptor optical window can survive the thermal and structural environments.
- Aero-optical effects. The interceptor bow shock wave and forebody window coolant will interfere with the seeker line-of-sight measurement.
- Shroud separation. The shroud must retain structural integrity during flight up to interceptor separation. It must separate uniformly to ensure no damage to the interceptor.
- Non-nuclear interceptor performance. This issue concerns reliability of performance and lethality of the interceptor to increase the probability of destroying an RV.
- Guidance and fuzing accuracy. This issue involves inertial alignment and navigation errors for long flights.
- Target acquisition in a nuclear environment. The operational interceptor must be able to acquire and track an RV in a nuclear environment.
- Performance and survivability of electronics in a nuclear environment. The electronics must be able to perform and survive in a nuclear environment.

These HEDI technology issues are summarized in Figure 5.5-2.

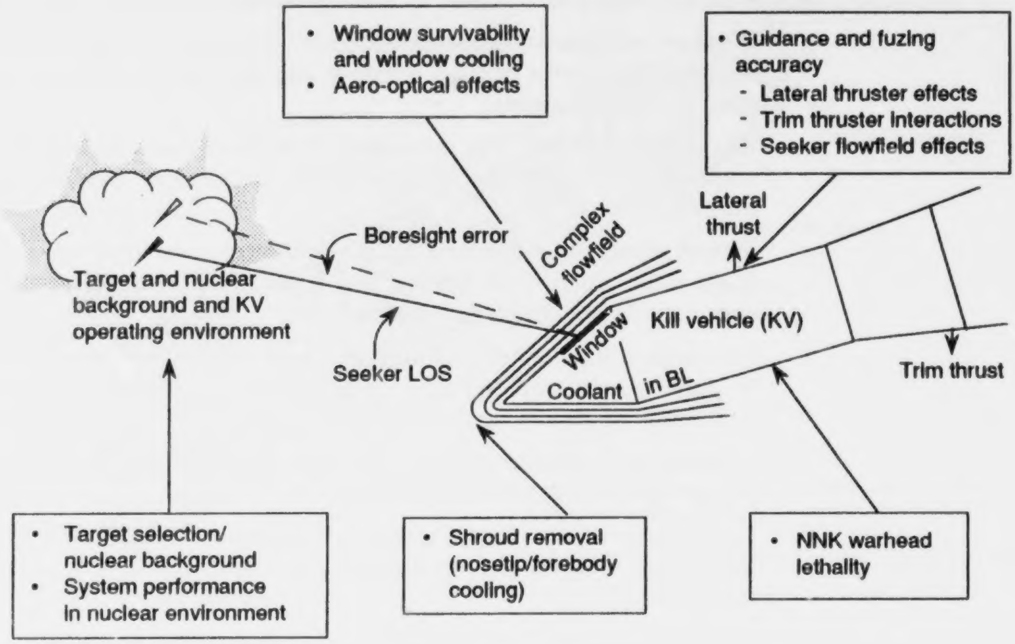
Tests that address the first five critical technology issues during the KITE stage are planned or ongoing. The remaining two issues, RV acquisition and performance and survivability of electronics in a nuclear environment, will be addressed during full-scale development.

Accomplishments

A 60-month contract was awarded in January 1986 to demonstrate the resolution of key technical issues through ground tests, simulations, and flight experiments.

In early FY 1988, an interceptor test verified certain predictions. Also, the first sapphire window of optical quality was delivered. Confidence that the shroud would separate as required was improved as a result of a wind tunnel test. The first imager and flight weight sensor assembly were fabricated and delivered in late FY 1988. Detonation of the interceptor warhead in the test arena demonstrated operation of the complete interceptor. The test scheduled in early FY 1989 should validate error

Figure 5.5-2
HEDI Critical Technology Design Issues



- Window survivability and window cooling
- Aero-optical effects
- Guidance and fuzing accuracy
  - Lateral thruster effects
  - Trim thruster interactions
  - Seeker flowfield effects
Lateral thrust
Boresight error
Complex flowfield
Target and nuclear background and KV operating environment
Window
Kill vehicle (KV)
Seeker LOS
Coolant
in BL
Trim thrust
- Target selection/ nuclear background
- System performance in nuclear environment
- Shroud removal (nosetip/forebody cooling)
- NNK warhead lethality

algorithms. The cooling effectiveness test scheduled during FY 1989 will validate temperature and thermal control.

The optical window must withstand thermal and structural environments and maintain transparency. The first window was defined in February 1988. To resolve the window thermo-structural integrity issue, sapphire windows have been fabricated and successfully tested for stability and optical quality. A sapphire window has been manufactured from the largest crystal grown in the free world.

Aero-optical ground tests have shown boresight errors to be predictable and blur to be less than early theoretical predictions. Algorithms for tracking the RV against a nuclear fireball are being developed and analyses and simulations will be used to ensure mission requirements can be met. Results to date show that the ability to characterize the image blur has been achieved.

All seeker flight hardware has been delivered and assembly of the first flight seeker is under way.

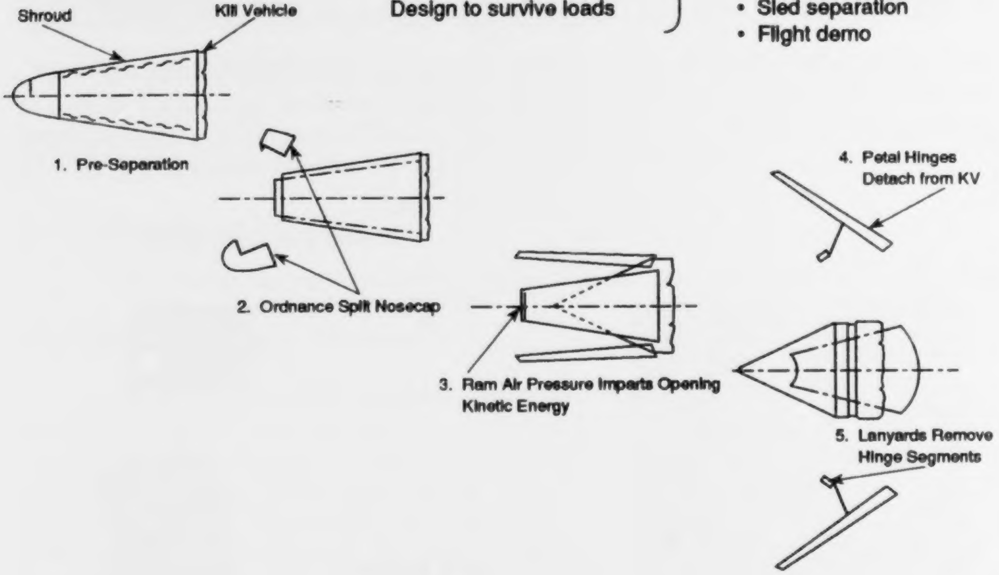
Ground tests have been successful in showing shroud separation and thermal protection capabilities. Figure 5.5-3 shows these results.

Figure 5.5-3
Shroud Separation Progress

Issues: Limit window cooling to homing only. Shroud removal without damage to KV or third stage.

Approach: Progressive development to flight demo.

Issue:	Solution:	Problem Resolution:
Window flyout protection	Protective shroud	MDAC airframe experience
Avoid damage to KV and third stage	Ordnance-initiated nosecap Ram-air shroud removal	Subscale Testing • Wind Tunnel Full-Scale Testing • Nosecap function • Static loads • Sled separation • Flight demo
Window/seeker survive shock	Controlled flyway	
	Minimize loads Design to survive loads	

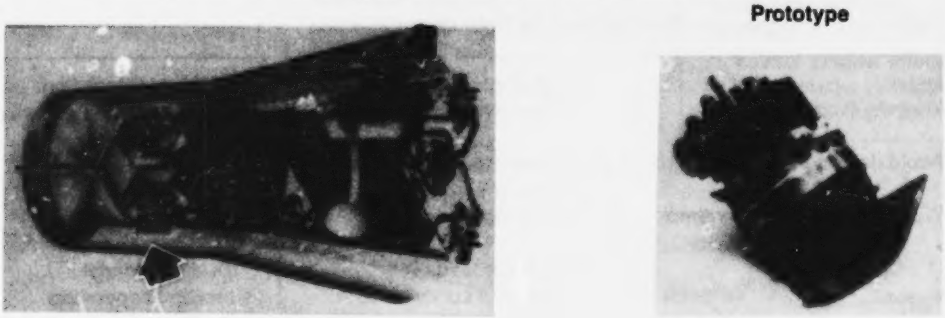

Shroud
Kill Vehicle
1. Pre-Separation
2. Ordnance Split Nosecap
3. Ram Air Pressure Imparts Opening Kinetic Energy
4. Petal Hinges Detach from KV
5. Lanyards Remove Hinge Segments

The reliability and lethality predictions of the kill vehicle have been demonstrated in ground tests and will be tested next during the KITE flights. Interceptor fragmentation tests in 1988 have been so successful that a design has been selected and further development and testing significantly reduced.

Control models have been created to understand the flow field effects caused by the jet interaction lateral thrusters in order to resolve the guidance accuracy issues. Forty-percent scale tests have successfully validated the body heating rate model and the prediction of no jet plume recirculation over the window.

The thruster sizes will be further reduced while ensuring proper thruster levels. The function will be validated in flight when the guidance and control loop is closed in KITE-3 to track and intercept the target. Significant advances in platelet technology have resulted in an advanced lateral thruster that delivers 10,500 pounds of thrust. Figure 5.5-4 shows these results.

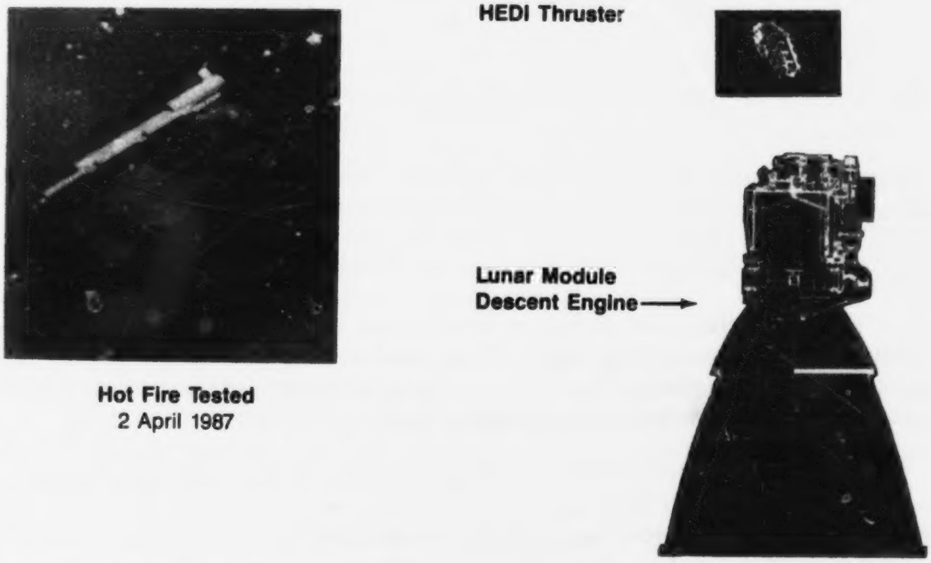
Figure 5.5-4
Compact, Fast-Response Control Thrusters for HEDI



Prototype

Lateral Thruster

Attitude Control Thruster



Relative Size Comparison

Hot Fire Tested
2 April 1987

Future Plans

KITE-1 will demonstrate interceptor and shroud separation, forebody and window cooling performance, and interceptor detonation, all in a free-flight environment. Also, the flight seeker and laser range finder for the KITE-2 interceptor will be delivered.

KITE-2 will demonstrate seeker acquisition of a near-stationary IR target through a sapphire window in a free-flight environment. KITE-3 will be a complete intercept demonstrating seeker, controls, cooling, fuze, and warhead against an actual instrumented target.

The second part of Dem/Val will focus on refining and finalizing the operational interceptor baseline design, developing the booster, and conducting a preprototype flight test to determine the optimal form, fit, and function of the downsized interceptor.

The original KITE portion of the HEDI project was structured to achieve the objectives discussed in the foregoing paragraphs culminating in five flight tests at WSMR. Funding decrements in FY 1987 and FY 1988 required a restructuring of the project to three flight-test programs.

Integrated tests involving experimental versions of sensors and command and control elements may be incorporated in the later flights at USAKA. More detailed planning will support the USAKA flights tests. During FY 1988, approximately $6.5 million was spent on the HEDI launch facility at USAKA.

5.5.2 Hypervelocity Gun

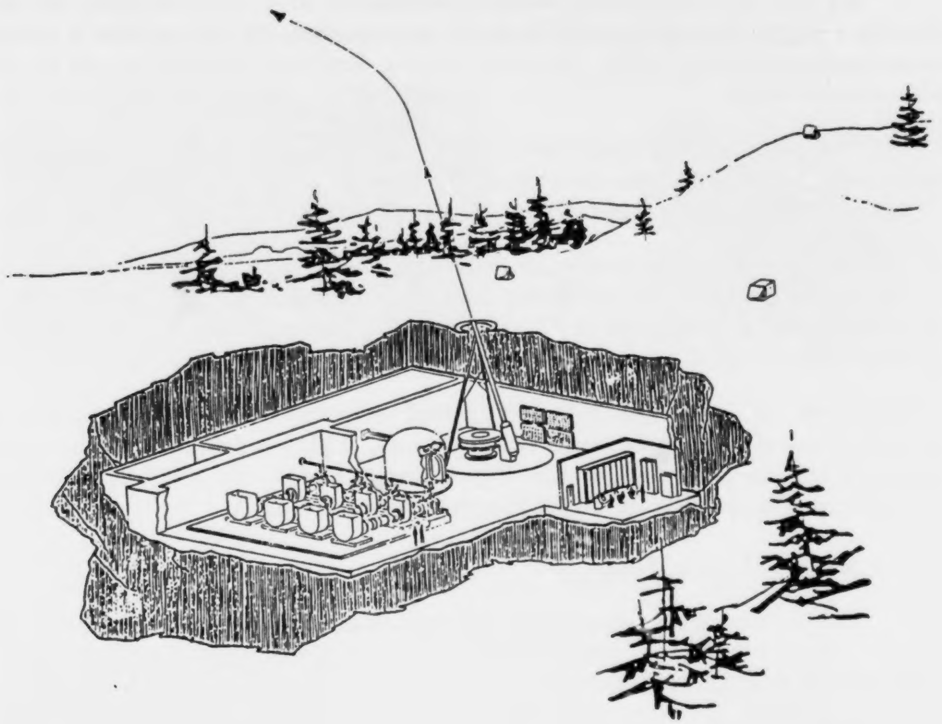
This section describes the HVG concept, its accomplishments, and future plans.

Concept and Project Overview

The HVG uses electromagnetic, electrothermal, and other advanced concepts to drive projectiles to extreme velocities. Ground-based HVGs at fixed sites could be capable of intercepting RVs and decoys at medium altitudes and could also have an antitactical ballistic missile role. HVGs on space-based platforms could intercept the threat in the boost, post-boost, and midcourse layers. Space-based HVGs are being examined for engagement of fast-burn boosters. Figure 5.5-5 illustrates the ground-based HVG concept, and Figure 5.5-6 shows the space-based HVG concept.

The HVG element is in the concept definition phase of the acquisition process. All HVG activities are currently technology base efforts performed in labs that research technical feasibility. Ongoing technology activities, described further in Section 6.3, will develop, integrate, demonstrate, and validate the technologies required for both the ground-based and the space-based HVG elements. This includes the launcher, integrated endoatmospheric and exoatmospheric projectile and fire control systems, and an integration validation program of digital emulation, hardware-in-the-loop, controlled ground hover testing, and focused free-flight kinematic experiments. Advances in projectile/fire control technologies, test facility capabilities, and test results will be made available to the other kinetic energy elements (i.e., ERIS, SBI, HEDI).

Figure 5.5-5
Ground-Based HVG Concept



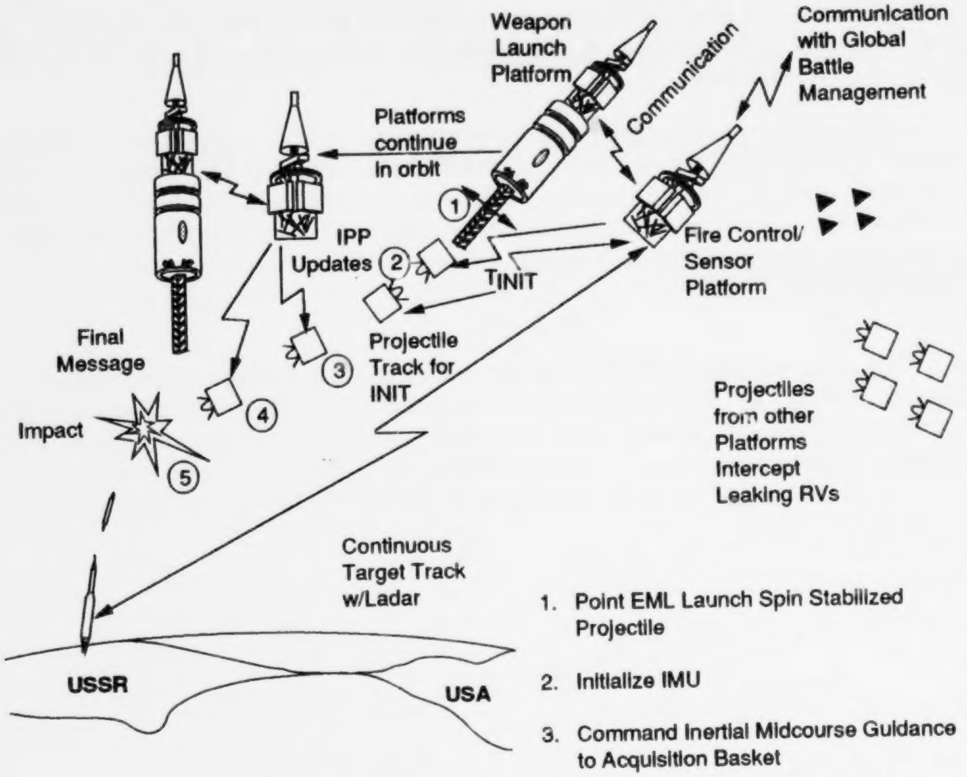
Technology Understanding

The key technical issues for the HVG are prime power, power conditioning, barrel life, efficiency, scalability, thermal management, energy recovery, and barrel slewing requirements. Priority issues are being addressed in SDIO programs managed by the Air Force and Army.

Key issues in the exoatmospheric projectile include 2-kilogram or lighter projectile, high-performance lightweight propulsion, high density electronics, highly sensitive seeker and acquisition, tracking and aimpoint selection algorithms, and high acceleration (100,000 *g*) launch and other environmental considerations. Some of these issues are being addressed in Phase I of the LEAP program. Issues such as high acceleration hardening for gun launch will be addressed in Phase II of the LEAP program.

Key issues for the endoatmospheric program are miniature IMU launch environmental compatibility (acceleration and electromagnetic interference in barrel), 10 *g* maneuvering, optical seeker, fire control accuracy, aerothermal interactions, and propulsion system design. These issues are being addressed in the Endoatmospheric

Figure 5.5-6
Space-Based HVG Concept


Weapon
Launch
Platform
Communication
Communication
with Global
Battle
Management
Platforms
continue
in orbit
1
IPP
Updates
2
TINIT
Fire Control/
Sensor
Platform
Final
Message
3
Projectile
Track for
INIT
4
Impact
5
Projectiles
from other
Platforms
Intercept
Leaking RVs
Continuous
Target Track
w/Ladar
USSR
USA

1. Point EML Launch Spin Stabilized Projectile
2. Initialize IMU
3. Command Inertial Midcourse Guidance to Acquisition Basket
4. Target Acquisition Handover to Autonomous Acquisition and Plume Track, Terminal Guidance
5. Handover to Booster Body Track, Final Maneuvers, Impact

Guided Projectile program whose goal is to develop and integrate subsystem elements of the projectile.

All HVG activities are presently in the technology development phase addressing weapon feasibility. However, progress has been rapid and guns already exist which have muzzle energies rivaling the largest main battle tank guns.

Accomplishments

Accomplishments in the HVG area include large-scale gun firings at multi-megajoule levels, rapid-fire gun development and test, dramatic increase in shots fired per barrel, increased gun efficiencies, completion of advanced material studies and initiation of experiments, testing of advanced opening switches, completion of the world's largest pulse power battery power supply to test large-bore rapid fire guns, and demonstration of greater than 75 shots on a single set of bore materials. Accomplishments in other DOD programs include 9 megajoule firings of single-shot lab guns, increased understanding of gun scalability, and initiation of research in other electromagnetic launchers.

Endoatmospheric projectile accomplishments include completion of baseline design capable of intercepts, completion of design analysis on aerothermal and mechanical stresses, launch stresses, maneuver boundaries, IMU baseline design, evolution of fire control concept, optical effects modeling, and propulsion subsystem design. Test plans have also been developed.

Future Plans

Ongoing research in HVG programs will continue to address critical technology issues as funding permits. Significant events include the testing of large-scale single shot and rapid fire guns with up to 20 megajoules of muzzle energy using the recently completed battery power supply. Ground-based HVG technologies are maturing at a sufficient rate to support a full-scale integrated testing of an antitactical missile HVG in the future.

Section 5.6

Follow-on Directed Energy Projects

5.6 Follow-on Directed Energy Projects

This section describes advanced concepts that could be included in the evolving SDS. In the phased approach to development, these concepts will be introduced into later SDS deployment phases as they reach technical maturity and as mission requirements change. Specific concepts discussed in this section are the ground-based laser (GBL), space-based laser (SBL), neutral particle beam (NPB), and nuclear directed energy weapons (NDEW).

Much of the work in directed energy projects is in the technology base and is therefore described in Chapter 6. This work and the system level efforts described in this subsection are an investment which will preserve long-term options in the face of an evolving Soviet threat.

Directed energy devices are exceptional candidates for ballistic missile defense missions. They possess unique characteristics such as speed-of-light delivery and long-range and multiple-shot capability that could significantly enhance the effectiveness and responsiveness of an evolving, sequentially deployed SDS. Because of these unique attributes, directed energy systems have the ability to perform all of the classic strategic defense roles, ranging from booster and post-boost vehicle destruction to interactive discrimination of advanced decoys in the midcourse layer. In addition, the advanced surveillance capabilities of these devices will enable detection and tracking of the missile, post-boost vehicle, or deployed reentry vehicles, and handover and designation of targets for space-based interceptors. Directed energy systems are capable of evolutionary growth from early boost-phase intercept capability to the performance levels required to negate robust, long-term responsive threats.

The directed energy technology program brings together research efforts addressing four basic concepts—SBL, GBL, NPB, NDEW—identified as promising approaches to meet the needs of a multitiered defense. Acquisition, tracking, pointing, and fire control efforts support all four of these concepts and are discussed following the basic concept subsections. In addition, there is a continuing level of effort in element formulation that also supports all of the directed energy concepts. This ongoing effort is designed to identify the technology content of the concepts in order to guide technology development and provide conceptual designs for evaluation in potential SDS architectures.

The SDI research program is focused primarily on non-nuclear technologies. However, to understand the potential impact of any such systems that the Soviet Union might develop as well as to determine the feasibility of these concepts for future SDI options, it is also critical that the program explore the feasibility of nuclear-driven directed energy concepts.

The most viable long-term SDS architecture would employ multiple defensive layers of kinetic energy interceptors, lasers, and particle beam devices that could engage ballistic missiles throughout their trajectory. This triad-like SDS structure, with two legs of DEWs and one leg of KEWs, would provide mutually reinforcing capabilities and positive synergism that would not be possible with a system consisting only of KEWs or DEWs. In the phased approach currently planned for development of the SDS, advanced concepts offer the promise of maintaining and/or improving system effectiveness even against a rapidly evolving threat.

5.6.1 Free Electron Laser/Ground-Based Laser

This section describes the free electron ground-based lasers and the technology advancement of those projects.

Concept and Project Overview

The development of the GBL element exploits the advantages of limiting the weight on orbit by retaining the beam generation function on the ground. The GBL employs laser devices based on the ground which generate an intense beam of near-visible radiation as shown in Figure 5.6-1. The high-energy laser beam is transmitted through the ground beam control subsystem, which corrects the beam for proper transmission through the atmosphere to the relay mirror spacecraft. The beam is then redirected to the input telescope of the mission spacecraft and focused on the target with the mission spacecraft output telescope. The GBL concept is conceived as a device capable of evolutionary growth in boost-layer intercept and interactive discrimination in midcourse.

The GBL project is structured to pursue a possible Milestone I decision in the early 1990s timeframe. Based on the results of the subsequent Dem/Val phase for each candidate, a Milestone II decision to enter FSD is currently planned for the mid 1990s. FSD will culminate in a prototype demonstration.

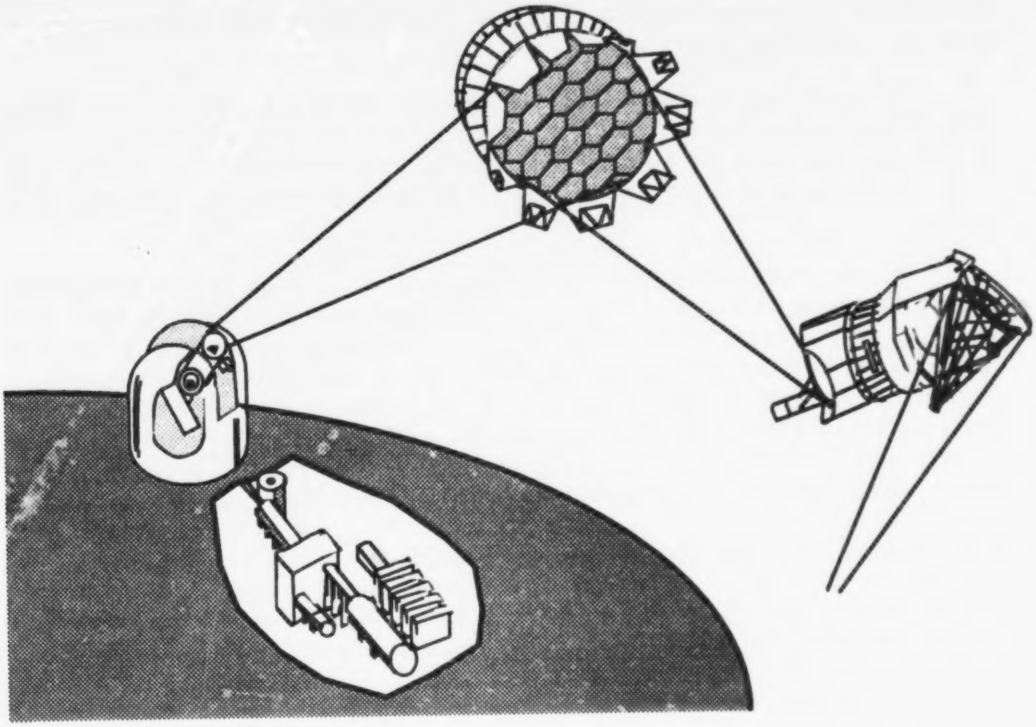
Technology Advancement

The description of the program in this chapter is focused on the achievement of the project goals dealing with system-level experiments and tests (e.g., the GBFEL TIE and the space segments). The major part of current efforts is in technology development which is detailed in Chapter 6.

The GBL project can be grouped into four concept-specific technical areas that must be pursued: device scaling; propagation and beam control; space optics and beam control, an area which is shared with other DEW concepts; and acquisition, tracking, and pointing, a functional integration area.

The ground-based FEL project is an intensive laboratory and field research project that will demonstrate the GBL technology needed to enter FSD. It is focused on five major objectives. First, the project will show that FELs can be built, integrated, and operated at multimegawatt power levels. Second, the project will demonstrate that a very high-power laser beam can be steered through a beam director, acquire and track a space target board, and deposit its energy on that space target. Third, the program will show that distortions on the laser beam caused by uneven heating of the atmosphere and other phenomena can be corrected and compensated on the ground

Figure 5.6-1
Ground-Based Laser Concept



using an adaptive optics subsystem. Fourth, it will demonstrate the systems integration and operation of a FEL, a beam control subsystem, and an atmospheric compensation subsystem. Fifth, the program will demonstrate the feasibility of a space-based relay mirror integrated with ground elements to validate the GBL concept for strategic defenses.

To meet these objectives, the ground-based FEL project is focused on three major areas of parallel research. The first is the Ground-Based Free Electron Laser Technology Integration Experiment (GBFELTIE). This experiment addresses the ground segment components of lasers, beam control, and adaptive optics. The second major activity of the GBL project is concerned with the space segments of the system. Here, relay and mission mirror spacecraft will be designed and subscale hardware fabricated during the Dem/Val phase. Once the GBL concept has been validated, a full-scale spacecraft will be designed and fabricated.

The third major focus of the GBL project deals with risk reduction and supporting technology. Issues of producibility, manufacturability, and quality assurance will be addressed. Of particular importance are the issues of nonlinear and cooled optics, large optical components fabrication, and coatings applications which are pursued in coordinated efforts with optics development in the chemical laser area. Because many of the ground and space segments of the GBL require high-quality optics, it is imperative that this area of technical research proceed in parallel with fundamental equipment research. The goal is to complete these efforts in time to support the Milestone II decision.

Essential functions of the GBL mission mirror satellite will be demonstrated by spaced-based experiments. The testing of the GBFELTIE with a space relay mirror will demonstrate all of the essential functions for a ground-based laser. A GBL with space-based components will be available for realistic integrated tests with other SDS elements.

To date, sufficient preliminary design of the GBL concept has been completed so that the design philosophy of the system elements has reasonably stabilized. As a result, the design approved for the GBFELTIE is structured to resolve the full range of technical issues related to transmitting lethal laser energy through the atmosphere. Similarly, the enabling technologies of the relay mirror have been developed to the point that the viability of this approach has been confirmed. Lastly, technical progress in large optics fabrication and test and beam control within the SBL program ensures that the developmental risk for the mission mirror is essentially engineering in nature.

5.6.2 Chemical Laser/Space-Based Laser

This section describes the chemical space-based laser and the technology advancement of this project.

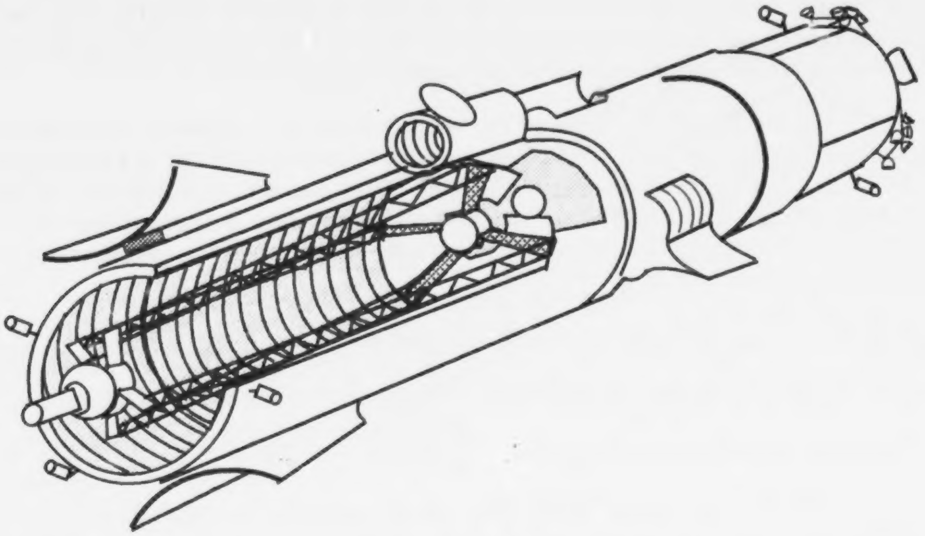
Concept and Project Overview

The development and deployment plan for the SBL element exploits the inherent simplicity of the hydrogen fluoride (HF) chemical laser and the economic and production benefits of modularity. The SBL consists of orbiting, highly autonomous, multimission battle stations (see Figure 5.6-2) capable of directing extremely powerful and agile infrared laser beams onto targets of interest. These battle stations could destroy missiles in boost phase down to the cloud tops. They could also provide interactive discrimination by destroying simple decoys (e.g., balloons) and thermally tagging or imparting a velocity change to more sophisticated decoys.

The system building blocks (modules) to be orbited initially are single aperture platforms. Their brightness is to be determined by the initial missions assigned to the SBL in a sequentially deployed architecture.

During FY 1988, approximately $0.3 million was spent on the repetitively pulsed chemical laser in Capistrano, California, to increase the run-time of this laser for pulsed lethality tests. Additionally, $0.4 million was spent for the development and installation of equipment to deliver waveforms similar to a free-electron laser for lethality tests.

Figure 5.6-2
Space-Based Laser Concept



The SBL project is structured toward a Milestone I decision in early 1992. Based on the results of the subsequent Dem/Val phase for each candidate, a Milestone II decision to enter FSD is currently planned for the mid 1990s. FSD will culminate in a prototype demonstration.

Technology Advancement

This description of the program focuses on the achievement of the project goals through system-level experiments and tests (e.g., Zenith Star and other space segments). A major part of current efforts is in technology development which is detailed in Chapter 6.

The critical technical issues for the SBL element can be grouped into five areas: laser devices; beam control; optics; acquisition, tracking, and pointing; and high power integration.

The primary effort in the area of the laser device involves demonstrating the feasibility and scalability of the HF chemical laser and associated optics. The Alpha laser will provide these demonstrations. A major beam control effort is the Large Optics Demonstration Experiment (LODE) project. LODE addresses the generic technical issues associated with the ability to sense and control the high energy laser wavefront in a dynamic environment. Complementing LODE is the Large Advanced Mirror Program (LAMP) which culminates in the fabrication and test of a large segmented space mirror. Similar to other directed energy concepts, technical issues relating to acquisition, tracking, and pointing are the focus of a common program responsive to the needs of all concepts.

Demonstration and validation of SBL technology will occur in the Zenith Star program. Zenith Star will ensure that the SBL remains a viable candidate for future deployments. The Zenith Star space experiments complete much of the Dem/Val phase for the space-based chemical laser. Zenith Star includes the integration of the Alpha laser, LAMP mirror, LODE beam control, and the acquisition, tracking, and pointing technologies for a series of high-power ground and space tests.

To date, the SBL concept has been defined in a series of conceptual design studies predating the SDI. These extensive trade studies have led to a technology base development program that began in the late 1970s and is currently providing the most mature DEW technologies. FY 1989 activities should demonstrate that major subsystems are ready to support integrated tests on the ground and system level tests in space by the mid 1990s.

5.6.3 Neutral Particle Beam Technology

This section describes the NPB concept and its technology advancement.

Concept and Project Overview

The neutral particle beam (NPB) project exploits the capability of a stream of atomic particles to penetrate into the target and provide lethal energies and/or induce signatures that permit discrimination. To interactively discriminate RVs from decoys by mass discrimination, a heavy RV hit by the particle pulse will yield a shower of neutrons and gamma rays that can then be detected by sensor systems. A light decoy yields a much weaker signal which is easier to discriminate. Such a beam is also capable of effecting electronics kill on launch systems in the boost and post-boost portions of the trajectory. The more robust NPB will increase target handling rates and will have the ability to attack and disable or destroy RVs in the midcourse region. When used for the boost/post-boost defense mission, the NPB concept consists of a number of platforms in space. When used for the midcourse discrimination mission, neutron sensor satellites are collocated with the NPB platforms in space. Figure 5.6-3 illustrates the NPB concept.

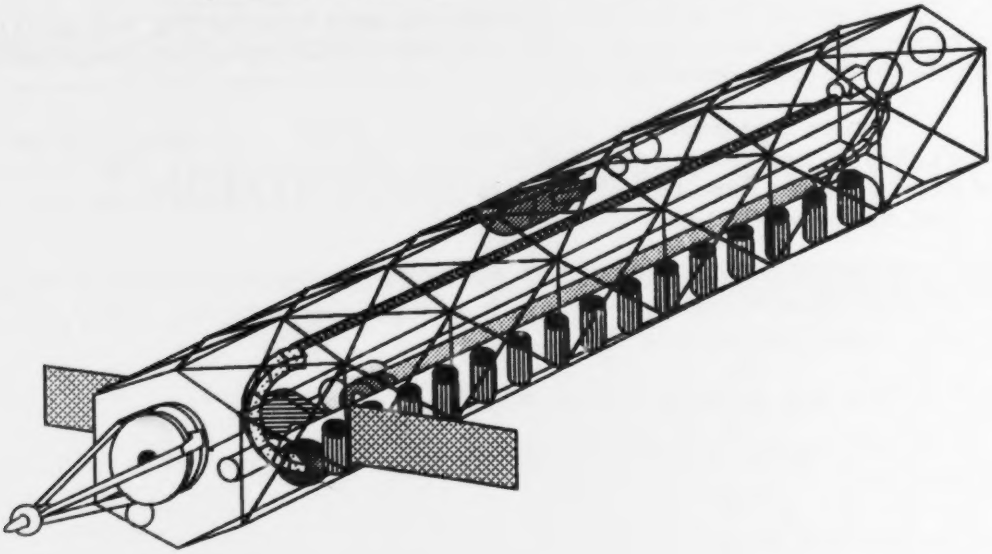
During FY 1988, approximately $6 million was spent on the NPB Ground Test Accelerator Facility and $5.1 million was spent on the NPB at Los Alamos National Laboratory to support NPB developmental tests.

The NPB project is structured to pursue a Milestone I decision in the early 1990s. Based on the results of the subsequent Dem/Val phase for each candidate, a Milestone II decision to enter FSD is currently planned for the mid 1990s. FSD will culminate in a prototype demonstration.

Technology Advancement

The focus in this description of the program is the achievement of the project's goals through system-level experiments and tests (e.g., Beam Experiments Aboard

Figure 5.6-3
Space-Based Neutral Particle Beam Concept



Rocket [BEAR], Pegasus, and other space segments). A major part of current efforts is in technology development which is detailed in Chapter 6.

There are a number of key technology goals which must be adequately addressed as the NPB concept evolves and the research, development, and acquisition process proceeds. These include the development of a continuous wave (CW) high brightness ion source, engineering scaling of both low and high energy acceleration, perfection of magnetic optic components, scaling of foil neutralizers, and optimization of beam sensing and pointing technologies. Programs to resolve these key issues have been formulated and are in progress.

The ground demonstration program consists of the Ground Test Accelerator (GTA), which will demonstrate the operation of an integrated NPB system with mission-capable performance parameters, and the Continuous Wave Deuterium Demonstration (CWDD) which will perform at high duty factors necessary for fast retargeting. Complementing the ground demonstrations will be experiments that address technical issues regarding operations in a space environment. BEAR, a suborbital experiment, will address the initial feasibility of an NPB accelerator operating in space while Pegasus, an orbital experiment, will use a GTA design-class accelerator to address in detail space operability issues.

To date, the NPB technology development effort has made significant progress in all technologies associated with an initial NPB device (whether used for destruction or discrimination). Every key part of the device has been demonstrated at the component level with unexpected progress being made in some cases toward achieving operational parameters.

Work on the ground demonstration segments is proceeding with the GTA facility ready for occupancy in mid FY 1989 while CWDD preliminary design review (PDR) occurred in December 1988.

Space experiments are also progressing. BEAR is scheduled for flight in FY 1989, having completed its critical design review (CDR) in FY 1988. Pegasus scope and goals were defined in FY 1988 and early FY 1989; a design contract scheduled by for FY 1990.

The weapon-level accelerator and optics tests demonstrated on GTA and CWDD, together with the lower energy space experiment in Pegasus, will resolve all major technical issues for the NPB.

5.6.4 Nuclear Directed Energy Weapon Technology

This section describes the NDEW technology concept and its technology advancement.

Concept and Project Overview

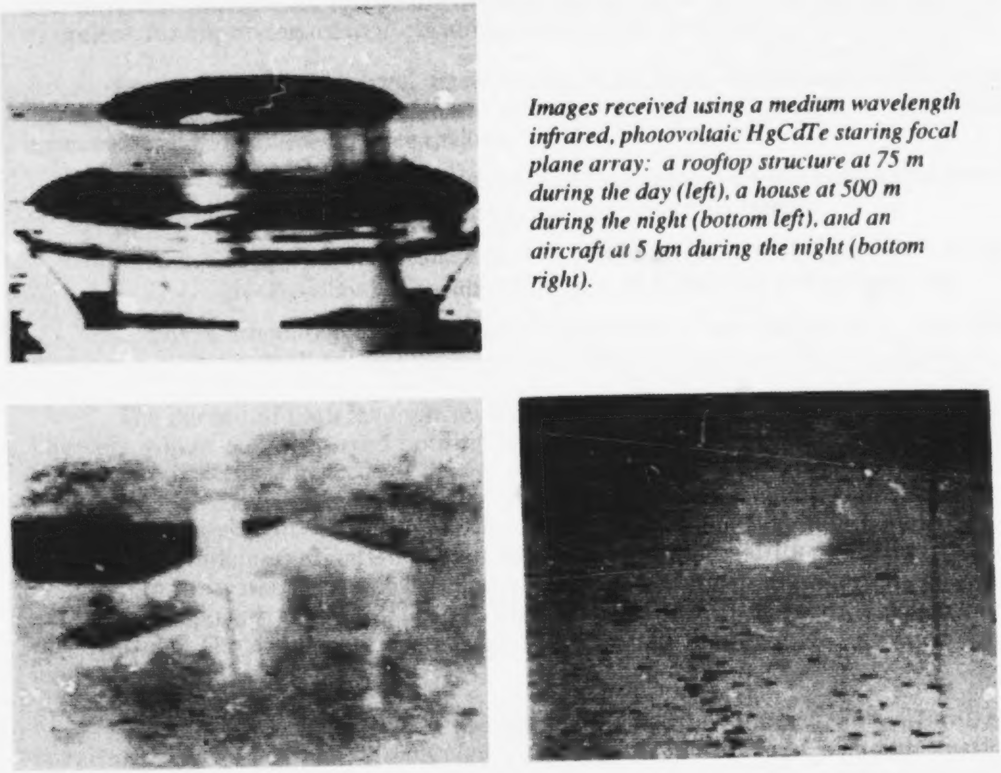
The Department of Energy, in support of the SDIO, has a broad-based research program investigating the feasibility of developing nuclear directed energy weapons. Several NDEW concepts are being studied, including X-ray lasers (XRLs), hypervelocity projectiles (HVPs), and optical lasers. These concepts offer fundamental improvements in defense technology, including high brightness, large lethal volume, multiple simultaneous target engagement, and alternative lethality mechanisms. Project details are described in Chapter 6.

Technology Advancement

Several dedicated underground tests have been conducted to support the NDEW technology program. Experiments and analyses also continue to support understanding of NDEW physics, with emphasis on weapon effects and diagnostics of output characteristics. The Department of Energy will continue NDEW nuclear underground tests. Determination of overall weapon concept feasibility will continue to be studied by DOD.

Chapter 6

Technology Base Projects



Images received using a medium wavelength infrared, photovoltaic HgCdTe staring focal plane array: a rooftop structure at 75 m during the day (left), a house at 500 m during the night (bottom left), and an aircraft at 5 km during the night (bottom right).

Chapter 6

Technology Base Projects

Sustained and focused technology advances are requisite to developing and maintaining a viable strategic defense system (SDS). Accordingly, the current SDIO program strategy balances both basic research and focused technology development with system development. The advances that have resulted from these balanced technology base efforts are necessary for a thoroughly reliable defense. They also serve to maintain the viability of Phase I deployments against potential Soviet responses. The aggressive pursuit of growth technologies is guided by the goal of blocking the Soviets from applying simple countermeasures to the SDS. Once this goal is achieved, the Soviets are forced to use expensive, complex countermeasures with an increased uncertainty of success. Visible demonstrations of technology achievements also have the potential for enhancing the arms control process by displaying a U.S. set of options for improving mission capability of the SDS over time.

To sustain the balanced basic research/focused technology and system development approach, the investment strategy applied to technology base efforts concentrates on the following three major elements:

- Continuation of work on mature technologies at a pace sufficient to support demonstrations in the early and mid 1990s.
- Aggressive pursuit of growth technologies with the greatest leverage for maintaining a viable SDS against a potential Soviet response.
- Encouragement of prompt exploration of new initiatives by reserving a small but significant portion of the budget for such investigations.

The pursuit of high leverage technologies has been focused on (1) boost-layer intercept where one destroyed booster removes multiple nuclear weapons from the battle and potentially hundreds of decoys of various types; (2) low cost interceptors for the midcourse where defended areas can be large and the intercept of sophisticated and expensive decoys and warheads can be cost-effective; and (3) active and passive surveillance, where elimination by discrimination of the majority of the decoys and debris from the warheads supports a cost-effective use of weapon resources. From the start, the emphasis provided by the President has been on several non-nuclear mechanisms. The numbers of candidate concepts continue to grow as new capabilities evolve.

Technology base activities are guided by the development of performance specifications and goals flowing from concept definition and systems analysis activities. To this end, the technology base program covers the entire spectrum of technology activities. Integrated experiments accomplish multiple objectives including feasibility and scalability of technical achievement. Fundamental laboratory research provides the flow of new ideas into the technology base. Conceptual studies, phenomenology investigations and experiments, and data collection projects are necessary support to the entire effort. These activities can be defined in the following three broad categories :

- Technologies in direct support of SDS Phase I that (1) support the Dem/Val tests and the FSD prototype and (2) support planned product improvement to the elements once SDS Phase I is deployed.
- Growth technologies, analogous to those supporting Phase I, that support the advanced concepts and which have the potential to maintain and/or improve mission capability of the SDS over time. These efforts produce the technologies that support the "branching and blocking" of Soviet responses to the SDS Phase I. They also yield advanced growth in performance or cost reduction for both Phase I elements and advanced concepts.
- Innovative technologies seeking "breakthroughs or quantum leaps" in improving the capability to perform the functions of the SDS.

The interaction between technology base and individual element development is key to meeting the demands of the DOD development cycle. This interaction can be characterized by two factors. First, in the early stages of element development, the technology base is focused on performance goals (not specification) that are defined by systems analysis and demonstration/validation activities. Their schedules are dictated by a combination of available resources and the progress of technology. Second, in the mature stages of system element development, the technology base is concentrated on meeting detailed performance specifications and element schedules that are focused on the design, fabrication, and test of the prototype and the eventual production of the element.

What follows is a comprehensive description of the SDIO technology base projects. Each project/task is described in four ways—technology goals, project description, accomplishments, and future plans. These broad based efforts are divided into nine categories. To begin, the sensor (Section 6.1), command center and system operation and integration functions (CC/SOIF) (Section 6.2), and interceptor technology (Section 6.3) discussions emphasize the technologies in direct support of Phase I SDS while describing growth technology development. Directed energy advanced growth concepts are described in Section 6.4. Key technologies that support both Phase I SDS and the longer term growth of SDS performance are discussed in Section 6.5, while Section 6.6 describes SDIO's role in developing space transportation. The technology base effort, which seeks innovation and breakthrough potential, is discussed in Section 6.7. Section 6.8 describes special efforts to transfer technology to other defense and private sector activities. Finally, Section 6.9 describes the efforts to fuse together into integrated experiments those needs that have common or similar experimental or test requirements.

Section 6.1

Sensor Technology

6.1 Sensor Technology

Sensor technology base efforts are designed to achieve the technology understanding described in Chapter 5, System Projects, as required for surveillance, acquisition, tracking, and discrimination of all segments of the target trajectory. Current efforts in the sensor technology base are distributed into six technology areas: signal processing, passive sensor technology, radar technology, laser radar technology, phenomenology, and discrimination technology. These efforts will support full-scale development decisions for the Phase I and follow-on SDS sensor elements, including BSTS, SSTS, GSTS, and GBR, with SSTS and GSTS combined in a midcourse sensor (MCS) program.

6.1.1 Signal Processing

This section describes the technology objectives and status of projects to develop signal processing hardware and software, primarily for SDS space assets.

6.1.1.1 Technology Goals

Large focal planes generate large data streams which must be processed in real time. Radiation-hardened very high-speed integrated circuits (VHSICs) with large throughput capacity will be needed for real-time data processing. On-board data processing technology requires small, fault-tolerant, low-power, radiation-hardened computers. The mission requires a mainframe processing capability beyond anything yet attempted on a military spacecraft. Robust algorithms are required to evaluate large threat numbers, determine individual threat object positions and velocities, ascertain missile types, generate state vectors, and predict impact points.

6.1.1.2 Project Description

The Signal Processing Technology project develops the advanced, radiation-hardened, very large-scale integrated circuit (VLSIC) technology needed for real-time signal and data processing on SDS spacecraft and interceptors. The project supports efforts to develop radiation-hardened circuit techniques and multi-application computer components and architectures. It seeks high-capacity electronics to process the extremely large volumes of focal plane data. For long-term reliability, weight, and power considerations, the technology of radiation-hardened electronics are pursued and uniquely designed for the particular sensor. Advanced architectures and algorithms will be of help in these areas and will drive the required signal processing capabilities, as will the particular sensor mission.

Long-duration spacecraft missions impose on electronics unique requirements not found in commercial applications. The ionizing radiation environment damages and destroys the basic transistors in integrated circuit electronics unless manufacturing techniques incorporate special materials and techniques. The cosmic ray environment can change data and instructions unless the design incorporates protective features. The man-made nuclear environment adds transient radiation pulses that can totally scramble a computer data base and force an operation to be restarted completely. This environment can also produce high fluxes of gamma and X-rays that could cause the electronics to fail. High intensities of neutrons can degrade or destroy the circuits, and X-ray heating can cause thermomechanical shock damage.

Spacecraft weight restrictions force computer designers to minimize power consumption to keep the power system small. Further, long-duration spacecraft must have highly reliable parts to minimize failures over time and must carry redundant (spare) circuits to allow remotely activated repair and replacement of failed circuits. Computers for strategic missiles and interceptors have similar issues across the spectrum of radiation effects, but with more emphasis on the transient nuclear weapons effects. These additional requirements force compromises in speed, density, and performance of spacecraft computers in comparison with ground applications.

6.1.1.3 Accomplishments

For an infrared sensor to perform its function, the analog signals from its focal plane must be converted to digital data. This will require analog-to-digital converters with greater dynamic range, higher speeds, and lower power than that currently available on radiation-hardened devices. These devices require advanced linear circuit technology, which has been neglected in recent years, with an emphasis on digital circuits such as VHSIC and the commercial market. It appears that a fabrication process that monolithically combines bipolar and CMOS circuit technology could provide the high speed and low power needed. In FY 1988, several contracts were awarded to develop radiation-hardened linear circuit technology.

Space-based signal and data processing designs will need tens to hundreds of microprocessor-based components connected together in a network that can operate in a fault-tolerant, reliable, and repairable manner. The Advanced On-Board Signal Processor (AOSP) program has developed a local area network that supports fault-tolerant, loosely coupled, distributed multiprocessors. A ground-based network of 24 data processors and 12 vector processors (with a capacity of nearly 1 billion floating point operations per second) has been demonstrated. The network performs the ground processing functions for a real-time satellite mission. This network demonstrates the capability to detect processing errors and to stop and replace failed processors while meeting mission performance. BSTS and SSTS contractors have used these concepts as the basis for their on-board processor designs.

All of the above computer systems will require massive amounts of high-density, high-speed random access memories (RAMs). All radiation-hardened RAM technology is based on static RAMs for reliable data retention, radiation hardness, and high-temperature operation. Radiation-hardened RAMs will constitute the majority of chips in a spacecraft on-board processor, which can require quantities of up to 10,000 or more. In FY 1988, several contractors demonstrated 64K static RAMs that exceed the radiation-hardness requirements for total ionizing dose, prompt dose upset, and single event upset (to cosmic rays) with no latch-up.

The combination of rapid technological progress and large system needs suggests that the next generation of 256K radiation-hardened static RAMs should be developed quickly because of their significant weight reduction benefits. Several contractors have designed and fabricated test chips that demonstrate the feasibility of rapidly moving to higher densities.

Because static RAMs can lose their data due to a power outage or prompt nuclear dose upset, spacecraft must have a nonvolatile means of data storage for programs and critical data. Current nonvolatile memory is based on magnetic phenomena (bubbles) or permanent charge storage (EEPROMS). These devices have poor operating characteristics in terms of speed, power, weight, hardness, and longevity. New technologies based on thin film magnetic and ferroelectric technology show significant promise in filling this critical need. Preparations to exploit these advances in feasibility demonstrations were completed.

Interceptors and midcourse sensors that will operate at lower altitudes will need circuits with high resistance to prompt nuclear dose upset. In FY 1988, one contractor succeeded in fabricating a 64K static RAM in CMOS/silicon on sapphire (SOS). Two contractors also succeeded in fabricating 64K static RAMs in CMOS/silicon on insulator (SOI), an improved method that promises improved yield and total dose hardness over CMOS/SOS. CMOS/SOI efforts during FY 1988 had promisingly high yields for 16K static RAM fabrication.

Work has begun to exploit special techniques that could enable systems to operate through a nearby nuclear event at levels up to the survivability capability of the electronics components. This could significantly simplify the design of the on-board computer systems. Initial efforts will focus on concepts based on SOI or SOS static RAMs with data storage capacitors, packaging, and special shielding. Prototype designs will be tested in aboveground facilities leading to a feasibility demonstration in an underground nuclear test.

Additional memory module efforts will address features such as error detection and correction at minimum power and speed impact, multichip module and high density interconnect packaging to reduce weight, self-checking pair computer modules to provide fault detection at the lowest level, and nonvolatile memory module design to retain critical code and data through power and nuclear transients. Efforts that will design, construct, and space qualify high-throughput, low-power, lightweight subassemblies were defined in FY 1988.

The data processors for SSTS will need more throughput and memory access than BSTS because of the larger number of targets. The radiation-hardened 32-bit (RH32) microprocessor combines the best of commercial reduced instruction set computer (RISC) research with the proven radiation-hardened VHSIC methodology established by the Generic VHSIC Spaceborne Computer (GVSC) program. The RH32 will have two to four times the throughput of GVSC, for comparable code, based on increased transistor count per chip, fewer chips, and pipelined floating point support. Several contractors have started RH32 designs; a competitive evaluation is expected to occur at the end of FY 1989; and delivery of radiation-hardened computer components is due at the end of FY 1991.

6.1.1.4 Future Plans

The radiation-hardened linear circuit technology contracts will begin to develop test data in FY 1989 and initial high-performance parts for testing are due in FY 1990. The AOSP network will be demonstrated in FY 1989 while performing real-time mission functions alongside three existing mission mainframe computers.

In radiation-hardened RAM technology, larger quantities of 64K static RAMs will be manufactured for radiation testing, reliability testing, subsystem demonstrations, and underground nuclear testing. For the next generation of 256K radiation-hardened RAM, contractors in FY 1989 will fabricate complex chips for evaluation as a step to a pilot line demonstration of 256K static RAMs in FY 1990.

Efforts to provide nonvolatile memory based on magnetic phenomena or permanent charge storage will start with new contracts in FY 1989 to design and test sample devices to demonstrate feasibility. Efforts to develop 64K static RAM in SOS and SOI will yield results permitting comparisons of yield and radiation hardness. Subassemblies will be tested in FY 1990. These tests will form the basis for expanding the capability for satellite and interceptor programs. An engineering baseline for yield improvement and producibility will be established.

The necessity for a single SSTS satellite to be capable of processing approximately thousands of simultaneous targets requires advances in both signal and data processing hardware. SSTS and GSTS will build on radiation-hardened VHSIC I (GVSC, 64K static RAM) and BSTS technology (AOSP, high-density computer and memory modules, 256K static RAM) to achieve higher capacity with RH32, monolithic wafer-scale integration, and advanced architectures. Gallium arsenide (GaAs) technology, which made possible a 50 MHz 32-bit central processing unit (CPU) chip in FY 1988, and VHSIC II technology, which demonstrated a 50 MHz beam-forming assembly in FY 1988, also have the potential to increase performance. In FY 1989, GaAs will be used to fabricate a 100 MHz CPU chip and radiation-hardened 16K static RAMs. In FY 1989, VHSIC II will demonstrate a radiation-hardened 50 MHz GVSC and the potential for moving to a submicron technology.

The SSTS and GSTS will have to perform high-throughput signal processing within a nuclear-disturbed environment. The sensitivity of focal plane arrays (FPAs) to nuclear debris will require complex, spike-adaptive algorithms to maximize the signal-to-noise ratio for target detection and tracking. Advanced monolithic wafer-scale integration promises the capability to efficiently combine throughput and memory to accomplish these algorithms and minimize power consumption. Two contractors will design and demonstrate feasibility of monolithic wafer-scale approaches in FY 1990.

6.1.2 Passive Sensors

As previously indicated, passive sensors activities have three major thrusts—above- and below-the-horizon FPAs, cryocoolers, and optics. Each of these are discussed in terms of project description, accomplishments, and future plans.

6.1.2.1 Technology Goals

This section discusses the technology goals of FPAs, large optics technology, and cryocoolers.

Focal Plane Arrays

The quantity of detectors required for BSTS FPAs is an order of magnitude greater than that for current systems, and greater sensitivity than that of current systems is required. These factors make producibility and cost important issues. In addition, the FPAs must be survivable in a nuclear and laser radiation environment. Thus, critical goals for these components focus on noise, speed, power, radiation hardness, and producibility.

Large Optics Technology

The producibility of large, lightweight, 1-meter-class, steep aspheric, high optical quality, radiation-hardened mirrors has not yet been demonstrated. While the sizes of optics for SSTS and GSTS are currently modest, the potential exists for growth to large optics to maintain sensor performance against an evolving threat.

Cryocoolers

To achieve the required sensitivity, LWIR sensors must be maintained at low temperatures, with optics slightly warmer. Because these temperatures must be maintained throughout the lifetime of the satellite, cryotechnology represents the most significant technological risk area in the SSTS project. The prototype flight cooler (PFC) program is under way to develop a cryocooler to meet this need.

6.1.2.2 Below-the-Horizon FPAs

This section describes below-the-horizon FPA projects and their accomplishments and future plans.

Project Description

The detection of hot missile plumes from space requires a sensor operating in the short to medium wavelength infrared region. Because the medium-wavelength infrared (MWIR) mercury cadmium telluride (HgCdTe) technology is the most mature technically, a major effort under the Manufacturing Technology (ManTech) program for HgCdTe has been underway during FY 1988 and early FY 1989. In the first phase, three competing contractors applied the lessons learned from manufacturing science for HgCdTe and demonstrated their "baseline" production of MWIR hybrid arrays.

Accomplishments

Two of the contractors successfully processed MWIR HgCdTe arrays and matching readouts The initial baseline expected a yield of 0.4 percent with a cost per pixel of $20. The baseline results are highly encouraging because the yield was greater than expected. Even more encouraging, the cost per pixel was much lower than the expected $20 per pixel. The baseline results were very near the intermediate goals of the second phase shown in Figure 6.1-1.

Figure 6.1-1
HgCdTe Program Demonstrations

Phase	Demonstrated Levels
Baseline (Months 4 through 6)	480 cm^2 into processing Current MWIR process Projected yield ~0.4% Pixel cost ~ $20
Intermediate (Months 21 through 23)	480 cm^2 into processing Improved process, throughput Projected yield ~1.5% Pixel cost ~$5
Pilot Production (Months 37 through 42)	3200 cm^2 into processing Production demonstration process Projected yield ~5% Pixel cost ~$1 - $2

Future Plans

The ManTech program will proceed through two additional process improvement phases before the contract ends in FY 1992. The intermediate process run of the second phase will be concluded in August 1989. Radiation testing of intermediate lots will begin in FY 1990 with emphasis on total dose survivability. Figure 6.1-2 is an example of the ManTech test arrays.

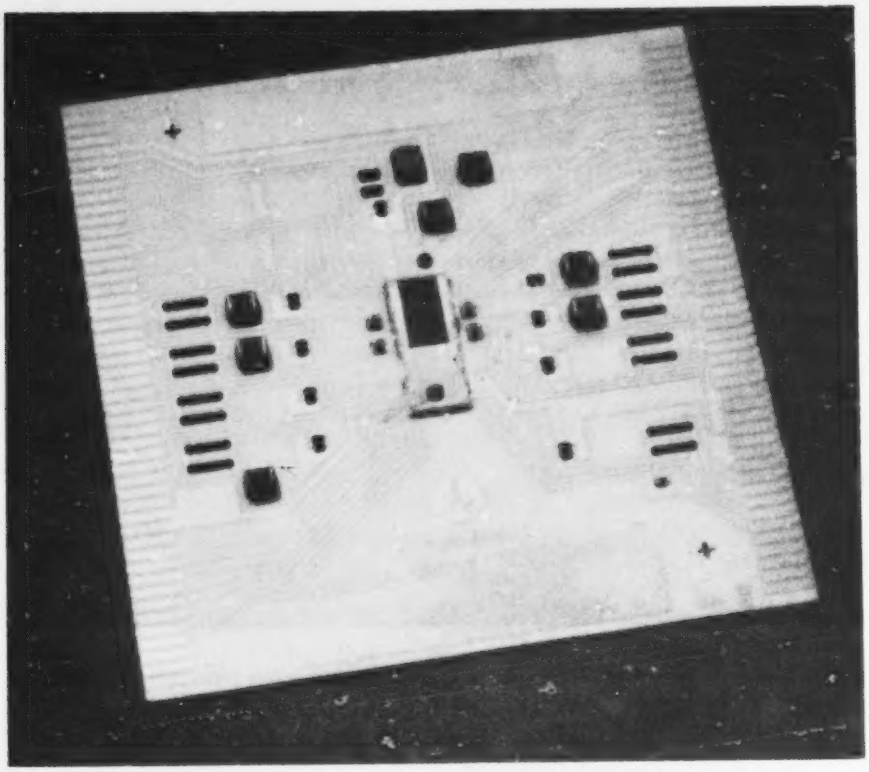
6.1.2.3 Above-the-Horizon FPAs

This section describes above-the-horizon FPA projects and their accomplishments and future plans.

Project Description

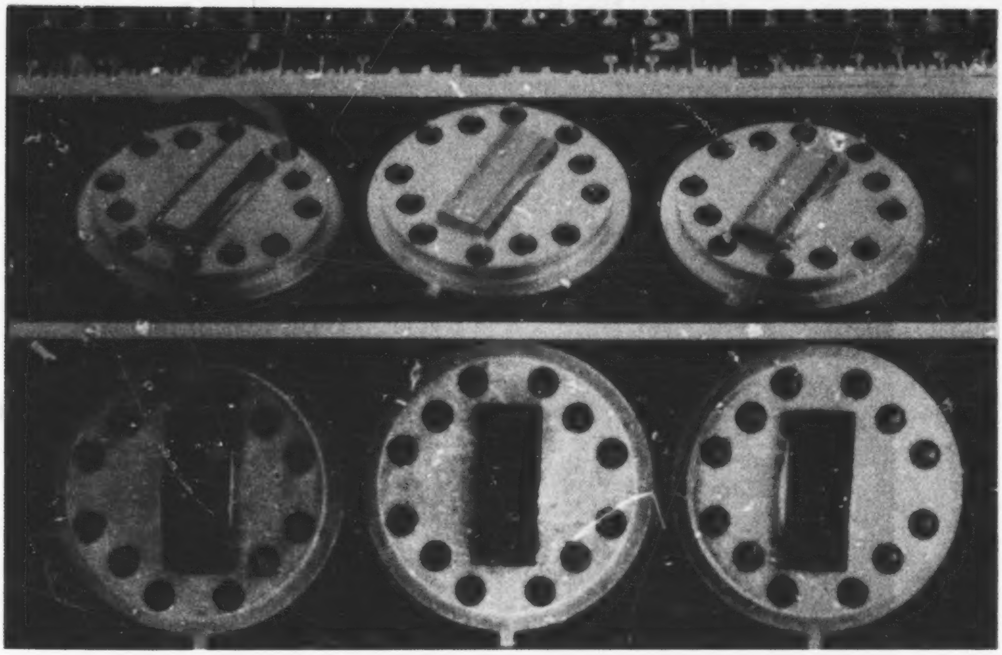
All midcourse sensors require relatively large, long-wavelength infrared (LWIR) focal planes to detect and track cold targets against a space background. The

Figure 6.1-2
Sample HgCdTe Technology Test Array



technology to manufacture these arrays has proceeded on a steady course—the critical issues being radiation hardness and producibility and, to a lesser extent, noise, speed, and power. Based on the need to survey large and distant areas of space, GSTS and SSTS are relying on the development of silicon-based impurity band conduction (IBC) technology to provide high-performance, radiation-hardened detector arrays. The technology has been developed and enhanced through the successful completion of first, the Sensor Experiment Evaluation and Review (SEER) program and, second, the Precursor Above the Horizon Sensor (PATHS) program. The recently initiated Hybrids with Advanced Yield for Surveillance (HYWAYS) pilot line production program is intended to further advance the technology, to resolve the remaining radiation hardness and producibility issues, and to provide extremely low noise readouts of the detector signals. The planned Midcourse Sensor Experiment (MSX) will utilize the devices produced under the HYWAYS program to provide verification of the technology. Figure 6.1.-3 shows examples of the SEER/PATHS IR FPA hybrids.

Figure 6.1-3
SEER/PATHS IRA FPA Hybrids



Si:As IBC	Si:Ga IBC Detector Array	Bulk Silicon

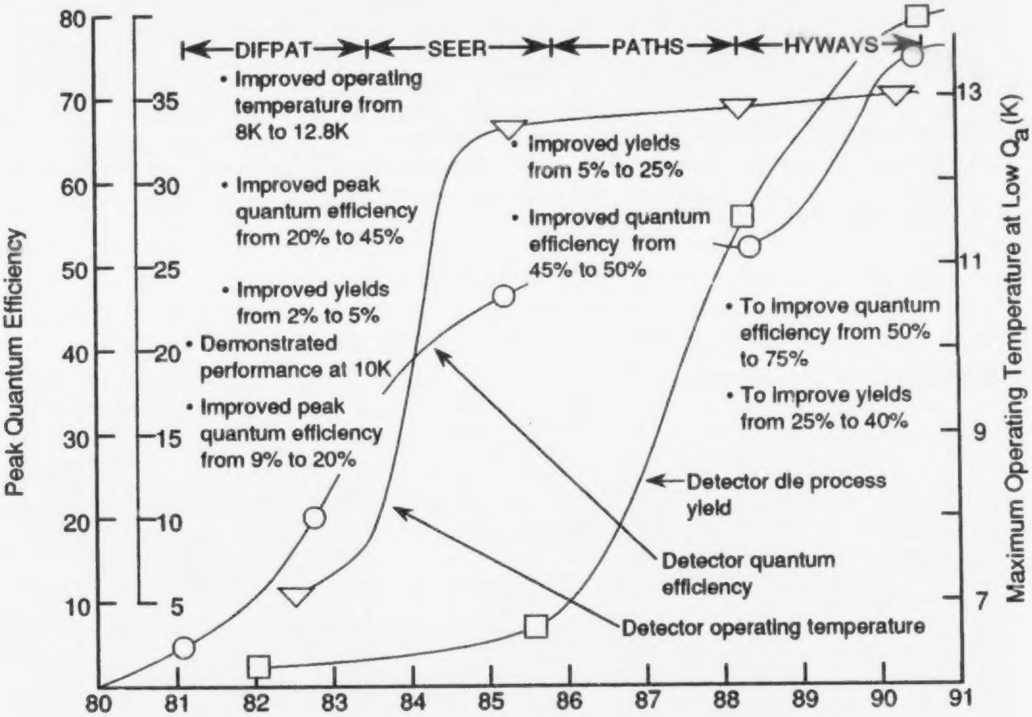
Accomplishments

The objective of the SEER program was to produce IBC hybrids on a larger scale than previous Air Force-Army R&D programs had attempted. SEER produced hybrids significantly faster than previous hybrids. This factor alone lowers the number of midcourse sensors required in orbit by allowing quicker revisit times. Additionally, the radiation test results of the SEER program confirmed that the IBC arrays are radiometrically stable, unlike conventional bulk silicon detectors. The SEER IBC arrays were able to operate in a dose rate environment 10^3 times greater (10^9 γ/cm^2-sec) than before. Total dose results indicate survival of SEER components to the megarad level. Finally, SEER IBC sensitivities were increased by a factor of three (Noise Equivalent Input [NEI] = 300 photons, vice 900 photons for conventional bulk silicon). All these technical achievements indicated superb progress unequaled by other IR technologies. SEER modules are currently being integrated into IR ground-based sensors for further evaluation.

The PATHS program built upon the results of the SEER program. PATHS emphasized process control of IBC manufacturing for producibility, lower noise readouts, higher radiation hardness, and module design for LWIR hybrids. The PATHS project fulfilled the objectives of higher sensitivities, lower power requirements, denser packing, and increased radiation hardness of hybrid arrays.

These achievements will allow midcourse surveillance systems to perform acquisition and discrimination at greater distances, scan the scenes faster, achieve higher resolution, and weigh and cost less. The PATHS program included the demonstration of pilot production line readiness with processing documentation during the prepilot line operation. More than 11,000 cm² of silicon material was processed resulting in more than 200 silicon hybrids meeting most technical requirements. Test facilities, including those for the evaluation of the detectors at cryogenic temperatures, have been successfully expanded, tested, and used. Under the PATHS program, advanced IBC detectors have been developed utilizing the achievement of the Boron Free Silicon program to provide high purity materials. Figure 6.1-4 summarizes the significant technical progress of LWIR IBC hybrids in yield, sensitivity, and operating temperatures. PATHS also developed a new generation of low noise readouts which are radiation hardened.

Figure 6.1-4
Si:As IBC Detector Development



Future Plans

Beginning in FY 1989, the HYWAYS program will concentrate on advanced technology (lower noise readouts, radiation-hardened hybrids) and demonstration of a pilot production line of Si:As IBC arrays by FY 1991. It is expected that during FY 1992 and FY 1993, advanced IBC technology will make the transition into the pilot production line. In addition to making available many IBC arrays for test and experimental use, the yield-cost-performance model based on HYWAYS will allow accurate cost estimates for system (SSTS and GSTS) focal planes. Additional radiation testing of SEER/PATHS hybrids will continue for the next few years.

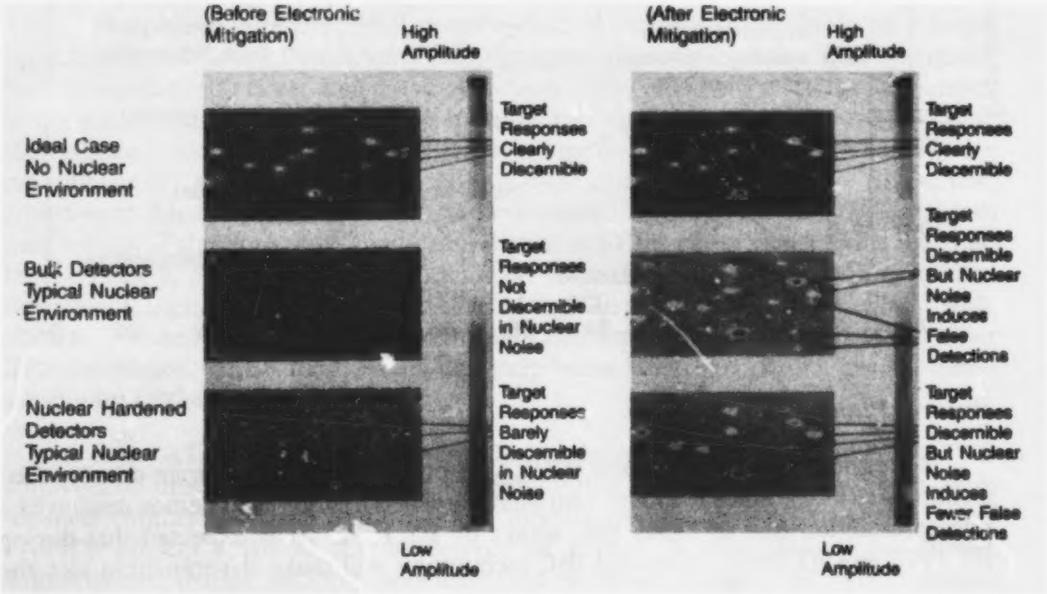
6.1.2.4 Other FPA Projects

Additional FPA projects include nuclear-hardened mosaic technology, an advanced component evaluation system, increasing LWIR operating temperatures, and On-Array Advanced Signal Processing.

Nuclear-Hardened Mosaic Technology

Further increases in the capability of detectors to operate in a nuclear environment have been made under this project. The Intrinsic Event Discrimination (IED) concept, an offshoot of IBC technology, could significantly reduce the noise induced in infrared detectors by gamma rays generated by a nuclear explosion. The combination of this technology with adaptive signal processing techniques to suppress the gamma noise has been validated in a laboratory environment in FY 1988. Research in this area will continue into FY 1989 to further exploit this critical technology. Figure 6.1-5 shows how a nuclear-hardened sensor using Spike Adaptive TDI (time delay and integration) signal processing can result in a much clearer acquisition of targets in a severe radiation environment. These accomplishments greatly improve the ability of midcourse sensors to not only survive the nuclear environment, but also to perform their functions in it effectively.

Figure 6.1-5
Infrared Sensor Imagery (Before and After Electronic Mitigation)


(Before Electronic Mitigation)
High Amplitude
(After Electronic Mitigation)
High Amplitude
Ideal Case No Nuclear Environment
Target Responses Clearly Discernible
Target Responses Clearly Discernible
Bulk Detectors Typical Nuclear Environment
Target Responses Not Discernible in Nuclear Noise
Target Responses Discernible But Nuclear Noise Induces False Detections
Nuclear Hardened Detectors Typical Nuclear Environment
Target Responses Barely Discernible in Nuclear Noise
Target Responses Discernible But Nuclear Noise Induces Fewer False Detections
Low Amplitude
Low Amplitude

Advanced Component Evaluation System

The ability to radiation test IR focal plane components at various national irradiation facilities has been greatly enhanced by the mobile Advanced Component Evaluation (ACE) system. It will be set up at White Sands Missile Range in FY 1989.

Increasing LWIR Operating Temperatures

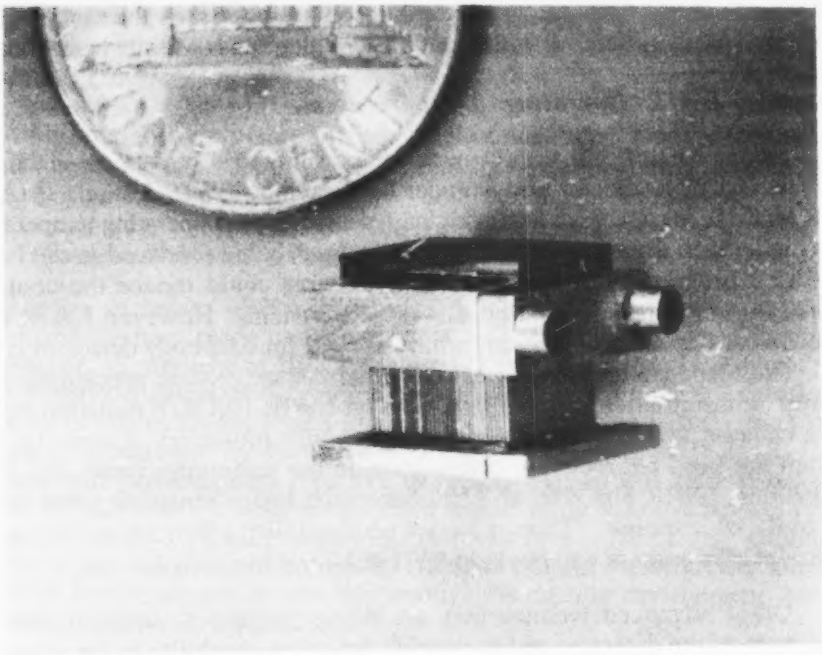
Another significant achievement is the continued improvement in the sensitivity of LWIR HgCdTe detector arrays under the Scanning LWIR Module (SLIM) effort. LWIR HgCdTe is capable of achieving high sensitivities at operating temperatures three times higher than the extrinsic silicon technologies being produced in the PATHS and HYWAYS programs. These higher temperatures could reduce the cooling power required for long-life, space-based surveillance systems. However, LWIR HgCdTe is still technically immature. The uniformity at 40°K for cold body detection is extremely poor. The response can vary over five orders of magnitude precluding any useful radiometric information. In addition, data on LWIR HgCdTe radiation response are sparse because few arrays have been successfully produced. Currently, the SLIM program has been redirected to concentrate on the uniformity issue. For interceptor applications, LWIR HgCdTe at 77°K has much lower sensitivity, but much better uniformity of response. Thus, a major producibility effort for radiation-hardened LWIR HgCdTe seekers will begin in FY 1989.

Other advanced technologies are being pursued to increase the operating temperature of the detectors and to provide detection capability in the very long-wave infrared region (greater than 27 micrometers). A study to investigate the feasibility of high temperature superconductors to sense IR radiation was initiated in FY 1988 with a national laboratory, and support has been provided to another effort in private industry that was initiated in FY 1989. Very high payoffs are expected in the areas of decreased power consumption, higher temperature of operation, and increased radiation hardness. Critical issues needing resolution are sensitivity and stability. The Heterojunction Interface Trap (HIT) and high operating temperature LWIR detector programs are investigating new HgCdTe growth techniques to both raise the operating temperature (from 77°K to 200°K) and increase the detection bandwidth.

On-Array Advanced Signal Processing

Another crucial area of passive sensor integration lies in the ability of the sensor to process large volumes of data coming off the focal plane. This problem has had significant impact on GSTS. The OASP project demonstrated the feasibility of stacking advanced signal processing chips to form a cube, upon which is mounted the IBC detector array. In FY 1988, the OASP cube was successfully fabricated twice and will be mated to IBC arrays in FY 1990 (see Figure 6.1-6). A major problem with this approach is heat dissipation. Advanced superconducting electronics for the OASP chips with suitable readouts are under development to lower heat loads.

Figure 6.1-6
Early Version of OASP Module



6.1.2.5 Cryogenic Coolers

This section describes cryogenic cooler projects and their accomplishments and future plans.

Project Description

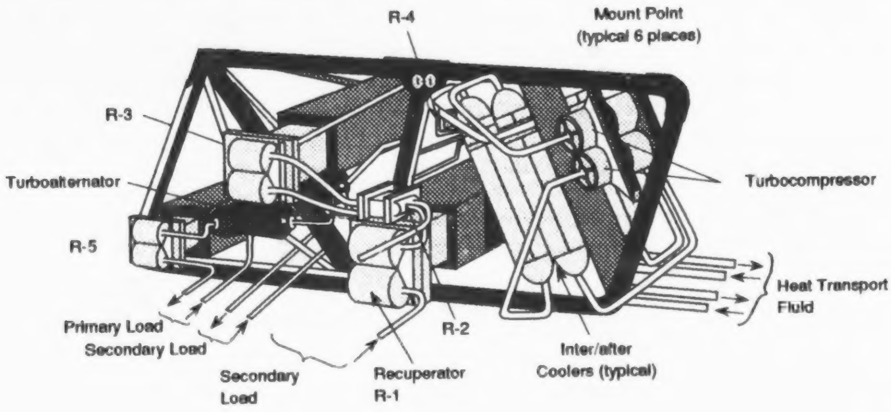
To achieve the required sensitivity, LWIR sensors must be maintained at very low temperatures. Because these temperatures need to be maintained throughout the life of the satellite, cryotechnology represents one of the significant technological risk areas in the SSTS program. Accordingly, risk reduction has been a central focus. Several approaches are being investigated that cover the full range of cooling needs—the Vuilleumeir (VM) cryocooler, the Reciprocating Rotating Refrigerator (R^3), and the Turbo-Brayton cryocooler. In addition, an advanced solid state concept is being investigated which could lead to a no-moving-parts cryocooler with extreme reliability.

Accomplishments

This program has demonstrated a cryocooler which meets the requirements of the SSTS under SDS Phase I. The VM machine was tested for 2.5 years, from 1984 through 1986, at twice the normal operating speed; this is equivalent to a 5-year (normal) operating test. However, because of wearing components such as bearings and seals, the Prototype Flight Cryocooler (PFC) program was initiated in FY 1986 to overcome such life-limiting mechanisms.

Two contracts were awarded for PFC coolers. The three-stage R^3 addresses heat loads below 2.5 watts. The three-stage Turbo-Brayton addresses loads above 2.5 watts, and is depicted in Figure 6.1-7. Both coolers demonstrated their respective critical third stage in FY 1987, and continue to gain confidence from their respective two-stage versions. Life testing of the two-stage R^3 and the two-stage Turbo-Brayton began in FY 1988. Mechanical cryocooler performance has been successfully demonstrated at most temperatures; however, associated electronic control systems for the PFC cryocoolers remain to be developed and proven for successful flight qualification. The advanced concept, a solid state approach, was initiated in late FY 1988. Other techniques based on advanced concepts reached important milestones in FY 1988. A device to provide cryogenic cooling based on the magneto-caloric effect has been built and proof-of-concept obtained. The magnetic cooler may be the most efficient third stage for PFC-like cryocoolers. The sorption compressor, which provides cooling by the absorption and subsequent release of gas, is also under evaluation.

Figure 6.1-7
Three-Stage Turbo-Brayton PFC Cryocooler



Future Plans

The PFC program is now concerned with the final design, fabrication, and integration of the R^3 and Turbo-Brayton coolers. These integrated subsystems will develop and validate the control systems as well. Pursuit of advanced concepts will continue to determine whether these promising approaches can meet future requirements.

6.1.2.6 Optics

This section describes optics projects and their accomplishments and future plans.

Project Description

Radiation-hardened, lightweight, mechanically strong, and producible optical components need to be developed for the surveillance and interceptor sensors. For surveillance sensors, the large size of the collection optics is a complicating issue. The wide field-of-view (WFOV) effort is the optics technology program for the midcourse surveillance sensors. Larger WFOV designs for systems like GSTS will significantly reduce the number of sensors required. Beryllium (Be) mirrors, a major part of this effort, will be used in the laboratory to evaluate the WFOV assembly.

Accomplishments

During FY 1988, point designs for WFOV systems were evaluated; the effort is now in the hardware development stage. The critical issue to be addressed is the stability of the optical components during cool-down.

A significant breakthrough in producing large, radiation-hardened Be mirrors was achieved in FY 1988. One of the techniques under development is based on replicating the mirrors from a master mold. Removing the mirrors from the mold without breaking them was very difficult. The discovery of a release agent, a material that facilitates the mirror-mold separation, will result in reductions in cost and time required to produce survivable Be mirrors for interceptor applications. Another technique, Be-on-Be, demonstrated excellent optical qualities for GSTS application (see Figure 6.1-8). During FY 1988, the ability to evaluate the optical quality across the entire surface of the mirrors has been automated. In addition, E-beam tests, used to simulate the X-ray portion of the nuclear environment, have indicated good survivability.

Future Plans

Wide field-of-view optics are scheduled to be demonstrated in FY 1991.

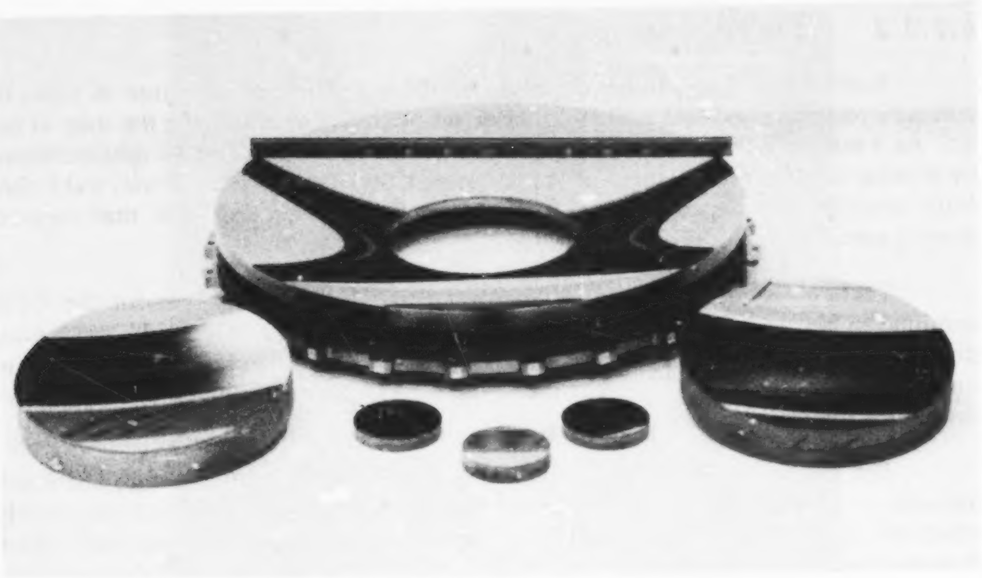
6.1.3 Radar Technology

This section addresses ground-based radar (GBR) technology goals and describes the GBR concept, accomplishments, and future plans.

6.1.3.1 Technology Goals

The GBR program has identified four key technical goals that are critical to the success of the GBR mission: radar performance, radar discrimination, nuclear effects

Figure 6.1-8
Be-on-Be Mirrors



mitigation, and electronic counter-countermeasures (ECCM) capability. To consolidate the discussion of discrimination, radar discrimination is discussed in Section 6.1.6. Similarly, backgrounds created by nuclear detonations are discussed in Section 6.1.5, Phenomenology.

Radar Performance

Three measures of radar performance are tracking accuracy, signal processing speed, and real-time imaging capability. The capacity for multiple target discrimination is limited by processor speed, design, and throughput. Traffic handling presents the major processing issue. Real-time imaging with an X-band phased array has not yet been demonstrated. The GBR-X experiment will provide estimates of handover volume, validate signal processor requirements, and provide the first data on real-time wide bandwidth imaging.

ECCM Capability

The GBR must be capable of defeating a wide variety of electronic countermeasure (ECM) techniques. Counter-countermeasure (CCM) methods are being developed.

6.1.3.2 Project Description

Radar technology, to be effective, must have a defined direction in order to conserve resources and still provide an effective approach to advancing the state of the art. As a mature technology, radar benefits from the operations and the data collected by existing sensors such as those of the Kwajalein Test Range, Cobra Dane, and Cobra Judy described in Section 6.1.5. These sensors are the test beds that support development of new ideas and identification of shortfalls.

Technology enhancements that offer improved performance for the GBR continue to be developed. These enhancements include wide bandwidth analog-to-digital converters that will provide the ability to use wide bandwidth waveforms to improve discrimination and real-time signal processors that support adaptive discrimination signal processing.

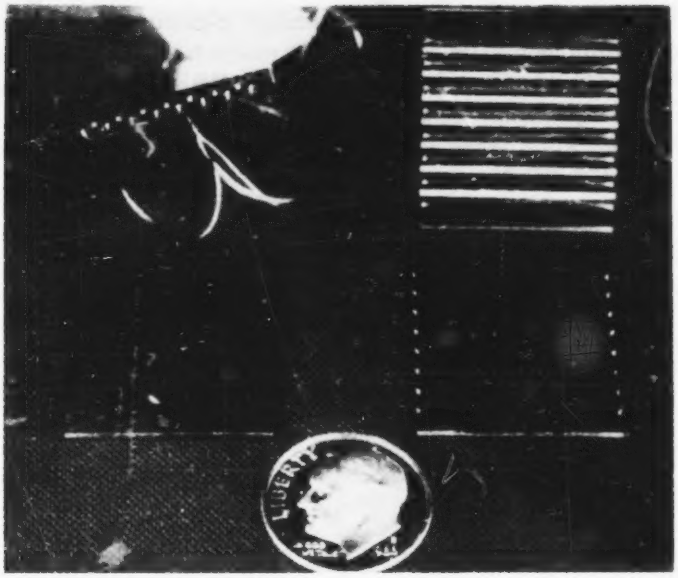
The solid-state phased arrays project is developing high-power, high-efficiency transceiver modules of the kind required for construction of a GBR. Using newly developed field effect transistor (FET) cells, a power amplifier has been built which demonstrates significant improvement in efficiency. A number of these devices could be combined to form a high-power, high-efficiency power amplifier which will help reduce the weight and costs of phased array radars while greatly improving their reliability. The resulting improved output and efficiency should greatly reduce the radar's power requirements.

Development of solid-state elements at higher frequencies is also under way. The development of linear and low-noise amplifiers, switches, power amplifiers, phase shifters, etc., using GaAs substrates constitutes the first step in investigating the capabilities of radars at higher frequencies. Research at these frequencies provides insight into the areas of nuclear effects mitigation, ECCM, and other areas, as well as the development of high frequency components needed in secure communications, interference avoidance, and other such functions in support of space-based assets.

Transmit/Receive (T/R) Module Development

A module validation project is demonstrating the performance and producibility of solid-state X-band T/R modules. A substantial number of modules have been produced and demonstrated to meet the required performance levels. Radiation and reliability tests for more than 100 of these modules are in progress. A subarray of 100 solid-state T/R elements has been fabricated to be used as the basis for long-term reliability testing. Combining these modules into a usable radar requires innovative ntenna design. A wideband, wide-scan subarray architecture has been developed for this purpose. The phase shifter design has been validated, a test feed system for the subarray fabricated, and measurements obtained which demonstrate the advantages of the solid-state technology (see Figure 6.1-9).

Figure 6.1-9
Millimeter Wave/Ferrite Phase Shifter Array



In addition, the development of similar components at another frequency is a necessary step in the eventual fabrication of transceiver modules for V-band phased-array radars. Progress to date includes the fabrication of a high-power amplifier, a low-noise amplifier, and rapid T/R switches. Phase shifters showing consistent performance across the wide bandwidth required for such applications have also been demonstrated.

A new computer program, Radar Technology Identification Methodology (RTIM), which uses expert systems technology to assist in the identification of requirements, is being developed to assess critical technology issues and cost/performance relationships. To date, radar technology progress includes the functional partitioning and definition of the software, a review of the expert systems package, and a review of the pertinent radar design codes. Cost relationships are being analyzed and the code will be capable of relating cost and performance issues.

Because all radars are subject to jamming, a variety of promising ECCM techniques are being investigated. The development of these techniques is intended to allow a microwave radar to operate successfully in a hostile environment despite the use of chaff or jamming.

6.1.3.3 Accomplishments

During FY 1988, a number of significant studies relating to GBR-X utilization and capabilities were performed. Many of these activities will continue in FY 1989 as well. Among these were analyses of discrimination performance in exoatmospheric and early reentry regimes, techniques for locating and discriminating targets in chaff clouds, the ability of the radar to counter enemy electronic countermeasures, and discrimination performance in nuclear radiation environments. These analyses served to validate the design concepts incorporated into GBR-X and to form a basis for developing detailed algorithms and operational procedures.

6.1.3.4 Future Plans

The GBR-X program will continue to participate in the discrimination efforts to develop techniques using real-time data obtained through earlier data collection efforts and to optimize overall discrimination performance. A critical design review (CDR) will be held for the GBR-X to be installed at USAKA for the GBR-X Dem/Val experiment.

Midcourse discrimination algorithms being developed in a parallel path to GBR-X will be integrated into the GBR-X design shortly after CDR. The GBR-X Dem/Val experiment will validate real-time, multitarget operation, midcourse imaging and discrimination of test objects as well as post-boost vehicle (PBV) observation and tracking. The GBR-X will validate acquisition, tracking, and handover functions via the Airborne Optical Adjunct (AOA) at the United States Army Kwajalein Atoll (USAKA). .

To support the Dem/Val test of the GBR-X, a facility is required to support a roof-mounted turret-type structure and to provide space for equipment, maintenance, and administration. No other unique facilities are required to support the GBR-X while at USAKA. However, normal USAKA support is required in the areas of logistics, maintenance, and power generation. Current USAKA power generation facilities may not be sufficient; additional power generation requirements for GBR-X are being studied.

In the third quarter of FY 1989, the results of the imaging studies conducted to address the impact and mitigation capabilities of wideband pulse radar in a nuclear environment will be presented. Predictions of the degree of mitigation of nuclear effects will be developed and limitations of the wide bandwidth system design will be established for a fixed set of conditions.

Definition and development of the GBR-X discrimination algorithms, signal processing, and related functions will be continued. Also an upgraded design for integration with ERIS will be initiated. The Operations in Nuclear Environment (OPINE) programs will continue and the continental United States (CONUS) test of the GBR-X will be initiated. Ground test data analysis and simulations will continue as well.

A test will be conducted to determine the effectiveness of the transmitter upgrade. The goal of the upgrade is to penetrate certain ECM capabilities. A series of studies designed to mitigate and defeat the ECM environment will be initiated. The CONUS readiness review will verify that the hardware and software design of the GBR-X supports multiple-target, real-time, high-throughput discrimination requirements.

6.1.4 Laser Radar Technology

This section addresses the technology goals and describes the various laser radar technology projects including their accomplishments and future plans.

6.1.4.1 Technology Goals

The overall goal of laser radar technology is to support both fire control and discrimination functions for the SDS. These developments can be categorized as shown in Figure 6.1-10. The requirements for a low earth orbit (LEO)-based system have been determined for the laser transmitter. Both CO_2 and solid state lasers have potential to satisfy the mission requirements for the LEO-based systems. These same functions of fire control and discrimination, which use non-imaging laser radars, can also be accomplished from medium earth orbit (MEO)-based platforms. However, in this case, the average power level increases by at least 10 times. An additional difficulty with the MEO basing is that each platform must handle more targets simultaneously, thereby making the beam agility requirements more stressing than for LEO-based systems. For discrimination purposes during the PBV phase, and for directed energy system fire control, high performance imaging sensors may be required. To achieve adequate signal-to-noise for each "element" of the target, the average power required increases over the MEO non-imaging case.

6.1.4.2 Project Descriptions

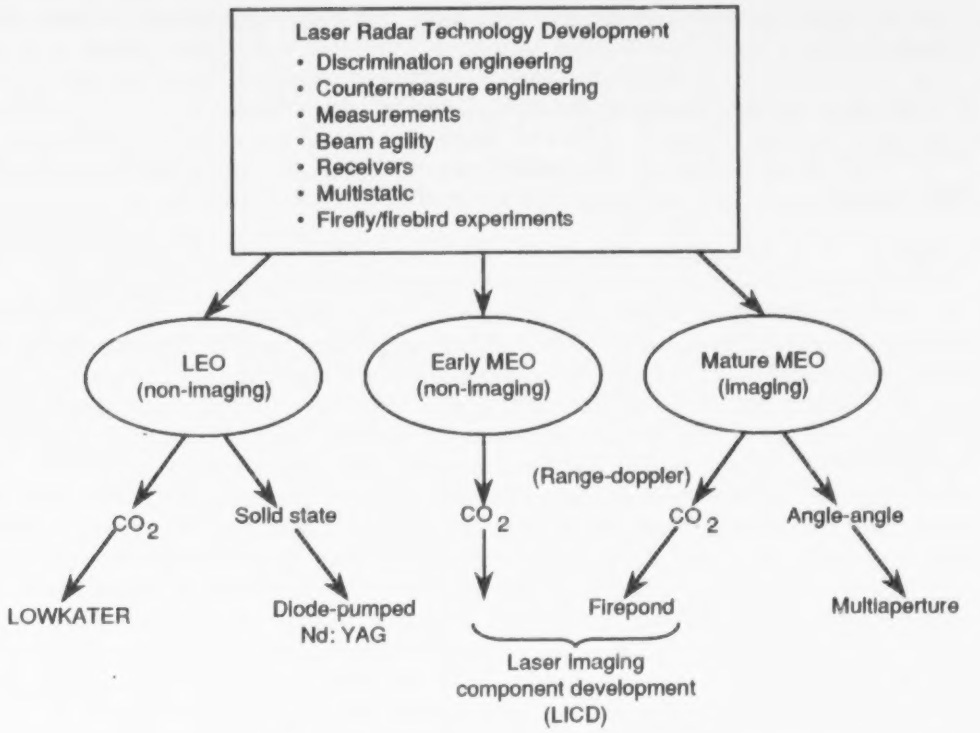
The Laser Radar Technology program will demonstrate the feasibility of all of the missions described above with a series of technology demonstrations that are described below.

The Low Weight KEW Active Tracker (LOWKATER) program will demonstrate a complete laser radar system, including transmitter, receiver, optics, and power conditioning.

The solid-state effort emphasizes diode-pumped Nd:YAG laser technology. The project will ultimately demonstrate a 10-watt average power system in the laboratory.

The MEO-based non-imaging requirements will be demonstrated as part of the Laser Imaging Component Development (LICD) program. This program will initially

Figure 6.1-10
SDIO Laser Radar Program


Laser Radar Technology Development
• Discrimination engineering
• Countermeasure engineering
• Measurements
• Beam agility
• Receivers
• Multistatic
• Firefly/firebird experiments
LEO (non-imaging)
Early MEO (non-imaging)
Mature MEO (imaging)
CO2
Solid state
CO2
(Range-doppler)
CO2
Angle-angle
LOWKATER
Diode-pumped Nd: YAG
Firepond
Multiaperture
Laser imaging component development (LICD)

demonstrate a high-resolution imaging capability at a low power level, followed by a demonstration at a high power level.

The existing Firepond laser radar will demonstrate a high-resolution imaging capability. This laser radar will then be used to measure specially designed targets flown by sounding rockets. Figure 6.1-11 depicts these experiments.

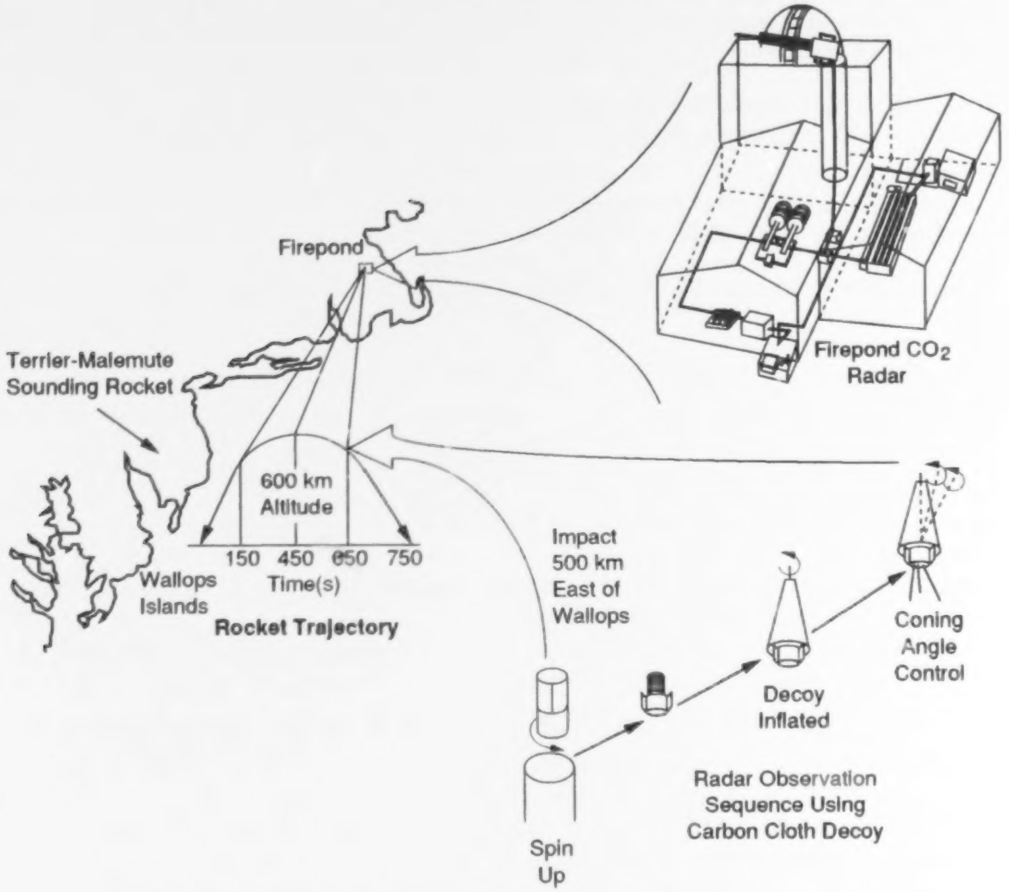
In addition, increased performance of laser receivers is sought in efforts to improve the sensitivity and increase the bandwidth of detectors.

The beam agility program seeks to provide laser radar systems with the ability to randomly address targets spaced across a wide field of view. It seeks to provide retargeting capabilities of a few thousandths of a second (milliseconds). The program is exploring such concepts as advanced hydraulics for beam steering, phased arrays of mirrors, and optical gratings.

6.1.4.3 Accomplishments

In the LOWKATER program, efforts continue on design and development, with the power conditioning unit for this class of laser already demonstrated.

Figure 6.1-11
Firepond CO_2 Imaging Radar Demonstration


Firepond
Terrier-Malemute Sounding Rocket
600 km Altitude
150 450 650 750
Time(s)
Wallops Islands
Rocket Trajectory
Firepond CO2 Radar
Impact 500 km East of Wallops
Spin Up
Decoy Inflated
Coning Angle Control
Radar Observation Sequence Using Carbon Cloth Decoy

For laser receivers, an increase of 35 percent in the sensitivity of the detectors has been achieved and the bandwidth of the detectors has been increased, which is necessary to achieve the imaging performance required.

The beam agility program is investigating a mirror structure and advanced hydraulics for beam steering which are capable of retargeting a laser radar beam in a reasonable time. Several unique concepts have been analyzed and are being tested in laboratory experiments. An alternative concept using optical techniques has matured to a low-power laboratory demonstration capable of significantly faster retargeting times.

6.1.4.4 Future Plans

Brassboard hardware for the LOWKATER program will be delivered and tested. Hardware that can be demonstrated in the space environment will be developed shortly thereafter.

The diode-pumped Nd:YAG project will demonstrate in the laboratory a 10 watt average power system, and work on a higher power system will continue.

The MEO non-imaging demonstration will occur, followed by a high power imaging demonstration.

The high resolution, imaging capability will be demonstrated. This will be followed with the tracking/imaging of specially designed targets launched on sounding rockets.

6.1.5 Phenomenology

Phenomenology efforts collect, analyze, and model phenomenology data. These activities focus on passive optical and radar observable phenomena, and impact all the SDS elements in some way. SDS sensor designs rely on signature data, of which little is presently known, to ensure that the system elements will perform as expected.

The experiments performed to collect these data also provide an additional benefit for system development. Design, construction, and operation of these advanced sensor experiments often require state-of-the-art technology (e.g., focal planes, optics) that is scalable, or similar, to that to be used in the deployed system elements. As such, these experiments provide experience in sensor integration and reduce the risk associated with applicable sensor technologies.

6.1.5.1 . Technology Goals

Background and plume phenomenology data are required for the design of exoatmospheric boost-phase sensors so that they can differentiate targets from hard earth and earth limb backgrounds. Booster and PBV signature data and plume/booster hardbody characteristics are also required for acquisition, track processing, identification, and algorithm development.

The MCS must identify RVs from a large and varied set of targets and masking devices. Potential penetration aids include chaff, aerosols, decoys, and antisimulation devices viewed against the earth limb or stellar background and, perhaps, in the presence of nuclear detonations. In addition, debris from deployment, tank fragments, and prior intercepts may be present. Passive optical techniques are considered viable in the near term.

Radars must also identify RVs from a large and varied set of targets and masking devices. Over the years, a great deal of phenomenology has been collected to support radar design, largely in the terminal phase of the ballistic missile trajectory. However, the SDI Program has emphasized operations at higher altitudes—the intercept of targets higher in the atmosphere and in space. This has placed new emphasis on collecting background and target signatures to support radar design and development.

In the future the SDS may require ground- or space-based sensors exploiting new phenomenology for midcourse discrimination. These sensors would supplement the passive IR sensors by providing more accurate update commands for the interceptors. The design and development of such sensors for space applications will also demand timely phenomenology data collection and analysis.

6.1.5.2 Project Description

Data collection, analysis, and modeling programs make up a trinity of interconnected activities. Models (and computer codes) represent knowledge gained or validated by data collection and analysis efforts. The evolving models are critically important to the evaluation and refinement of key sensor system functions such as acquisition, tracking, and discrimination. Several of these programs are described in the sections that follow.

Background Programs. CIRRIS 1A, depicted in Figure 6.1-12, is a Shuttle-based cryogenic IR sensor primarily designed for collection of earth and earthlimb backgrounds data in the spectral bands and at spatial resolutions applicable to BSTS. CIRRIS will also provide high quality spectral data of interest to the MCS. The orbit and mission duration of the Shuttle mission will permit CIRRIS to collect background data on a global scale.

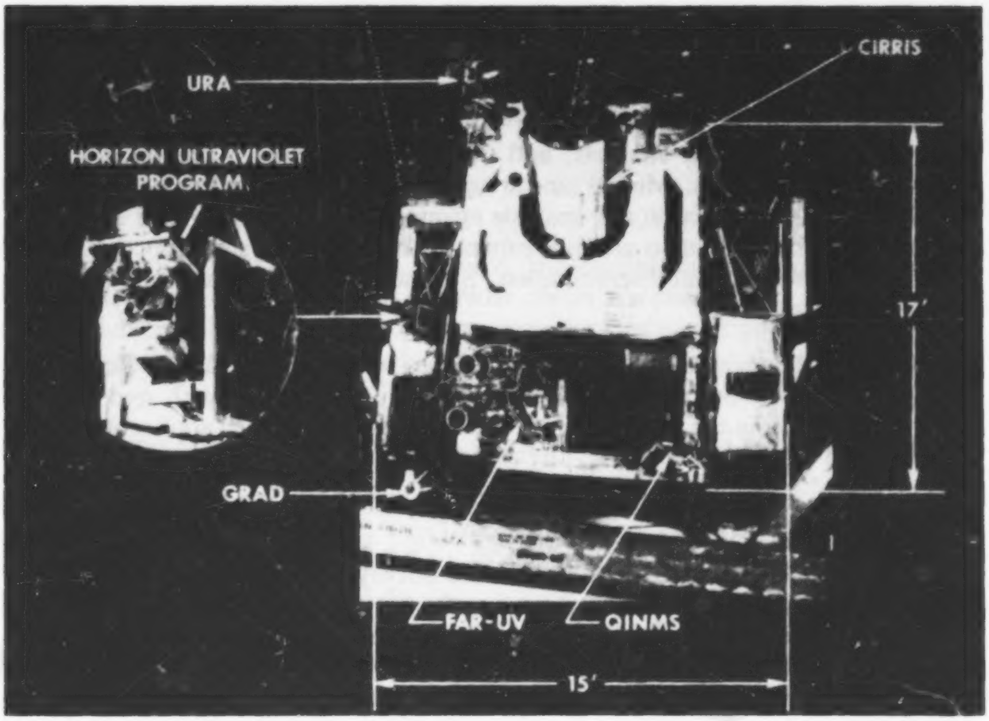
The Infrared Backgrounds Signature Survey (IBSS) experiment will collect radiometric data that will be of great utility for SDIO system definition. The system will be deployed on a detached, but controlled, pallet to observe and to collect data on Shuttle engine firings. Earth and earthlimb data will also be collected. IBSS and CIRRIS will perform some contamination measurements to assess the cleanliness of the Shuttle bay for future missions.

Spirit II is similar in design to CIRRIS 1A with two important differences. The spatial resolution of Spirit II is better than that of CIRRIS and directly supports MCS requirements. Secondly, this sensor is launched from a sounding rocket with launch time determined by high auroral activity. Spirit II uses a state-of-the-art optical system and the advanced IBC SEER/PATHS focal planes.

Spirit II will have a high probability of collecting auroral data, but the data will be of limited extent due to its six-minute flight. Spirit II also has contamination monitors on board to assess the cleanliness of a probe-launched sensor. This is a critical issue to a GSTS system. It is planned for launch in January 1991, so as to observe the auroral region near the maximum in the solar cycle.

The Three Color Experiment (TCE) is an add-on to the existing focal plane array on an existing experiment. It provides two additional spectral bands. TCE was

Figure 6.1-12
CIRRIS 1A



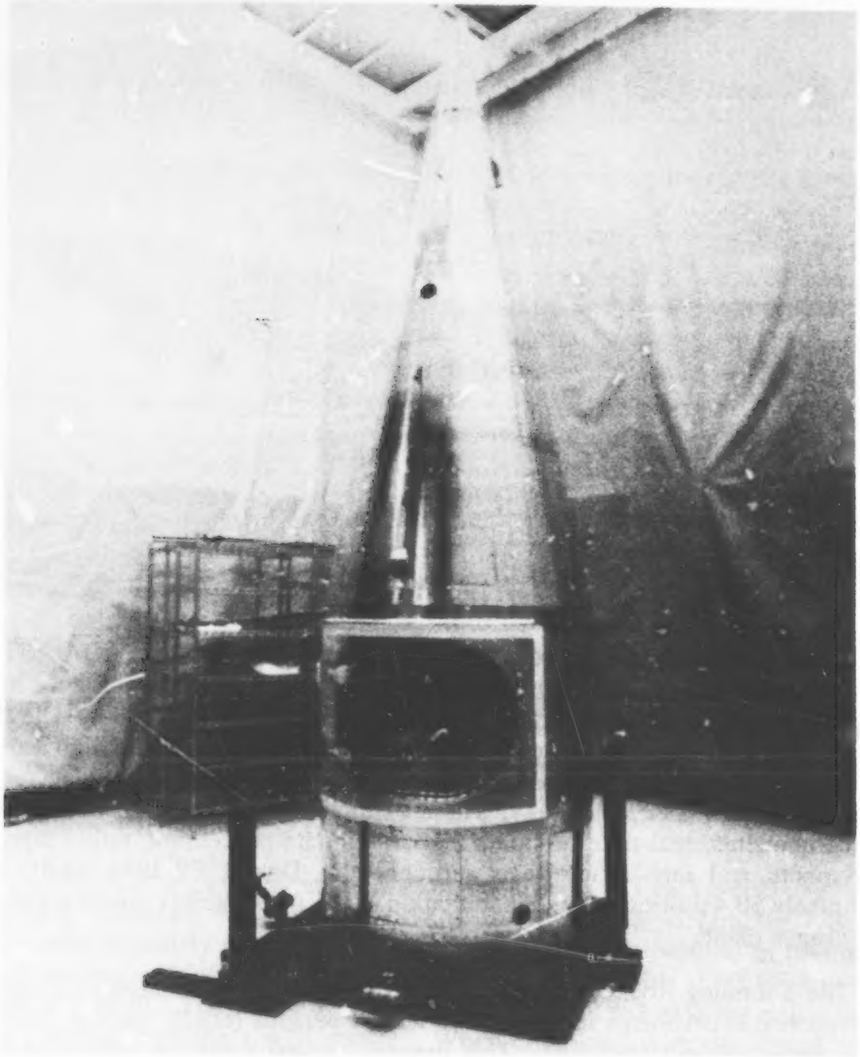
primarily intended to collect data on bright clouds that can create a clutter problem for a BSTS, SBI, or MCS. Data will also be collected on upper stage booster emissions.

The Visible Ultraviolet Experiment (VUE) is a separate sensor. It can be pointed and operate independently of the prime sensor (unlike TCE), and uses the same telemetry links as the host satellite. VUE collects data and provides relatively good spatial resolution. VUE will investigate to see if there are useful adjuncts to the IR for some SDS system functions. Experiments will address midcourse handoff, UV plume phenomenology, satellite attack warning, space object cataloging, and background phenomenology.

Excede III is designed to collect data that will improve the accuracy of nuclear predictive codes. It is a probe-launched dual payload that will separate into two separate packages. One module contains an electron gun for injection of high energy electrons into the atmosphere where they excite reactions and radiation from the atmospheric constituents. The second module contains numerous sensors for measurement of these reactions/emissions. The electron-rich environment simulates that expected near nuclear detonations.

Target Programs. The Queen Match (QM) sensor collects data during the midcourse phase and consists of LWIR detector arrays for radiometric data collection and discrimination algorithm evaluation. A mosaic detector element is part of this new detector technology. Queen Match is shown in Figure 6.1-13.

Figure 6.1-13
Queen Match



The Optical Aircraft Measurement Program (OAMP) is an aircraft-borne LWIR sensor for collection of late exoatmospheric data on targets. OAMP tracks and collects multispectral data. Figure 6.1-14 depicts the OAMP aircraft during structural flight test.

Figure 6.1-14
OAMP

The Airborne Optical Adjunct/Airborne Surveillance Test Bed (AOA/AST) has two major goals. The first is the validation of airborne LWIR surveillance sensor system functional performance. The AOA sensor is shown in Figure 4-4. The major functions to be validated are long-range acquisition, discrimination, and high accuracy track and handover to a ground-based sensor. The second goal is to provide a test bed for advanced surveillance technology. These technology advancements include LWIR sensor components, real-time on-board signal and data processing, target signature measurements, and aero-optic effects and controls. During FY 1988, SDIO spent approximately $0.4 million on the rehabilitation of the AOA facility power supply and liquid nitrogen plants.

The Sounding Rocket Measurement Program (SRMP) consists of a series of probe-launched experiments in which a variety of penaids (chaff, replicas, balloons, etc.) are deployed and observed. This program investigates the deployment and dynamics credibility of penaid designs and collects spectral data on their signatures to aid in discrimination algorithm design. This series of measurements is critical to understanding potential penaid signatures and to the development of robust passive discrimination techniques.

The Midcourse Sensor Experiment (MSX) is a multimission experiment. It is a multiyear satellite-based sensor package for collection of data required for development of MCS systems. MSX builds on a technology legacy and will serve to reduce the technology risk of Phase I MCS elements. MSX will devote most of its time to collection of celestial and earthlimb data. LWIR sensor characteristics are similar to those of Spirit II, but MSX will provide an extensive data base compared with Spirit II's 6 minutes of data.

The Exoatmospheric Discrimination Experiment (EDX) consists of a series of ICBM flights launched from Vandenberg and targeted into the USAKA area. The deployed missiles will be viewed over their flight paths. These measurement opportunities, for the most part, result from the integration of existing sensor assets.

Just as the MSX sensor contains advanced technology that may be drawn on for an SSTS sensor, the upgraded QM sensor may provide technology options for the GSTS sensor system. The detector arrays and optics are state of the art and are installed in the QM gimballed sensor payload.

Discrimination algorithm development and evaluation are in progress using recorded data. Millimeter-wave radar will provide real-time discrimination capability. For further discussion of discrimination algorithms, refer to Section 6.1.6.

Finally, in direct support of systems needs, a Strategic Scene Generation Model (SSGM) is under development. SSGM will provide a standard for the development of two-dimensional scenes for evaluation and development of sensor algorithms and designs. The modular SSGM architecture will contain all relevant industry standard codes and data bases for scene construction. This activity has already supported the BSTS contractors in FY 1988, and expects to begin aiding MCS efforts in FY 1989.

6.1.5.3 Accomplishments

A number of experiments, measurement programs and modeling efforts are under way or being developed to address MCS background and target issues. Midcourse target data programs include Cobra Eye, Queen Match, Cobra Judy, and AOA, SRMP, MSX, and EDX. Background experiments applicable to an MCS include IBSS, CIRRIS, Spirit II, MSX, Excede, and VUE.

AOA/AST is currently in integration, but all sensor, signal processing, and data processing hardware have been delivered to the prime contractor. Software development is nearly complete. The equipment will be installed in the modified aircraft and begin CONUS test flights in late FY 1989. Flights at USAKA will begin in early FY 1990. The major accomplishment in FY 1988 was the delivery to the prime contractor of the LWIR sensor. When combined with the signal and data processing equipment previously delivered, the AOA sensor system will have advanced the state of the art in many areas critical to SDI. FY 1989 accomplishments will include the completion of the integration and test process and the completion of the CONUS test flights. Another significant accomplishment has been the completion of plans to transform AOA into a surveillance test bed, the AST. This change is being implemented to provide a system to test surveillance hardware and software which will support resolution of SDS performance issues, especially with regard to midcourse.

Other specific accomplishments include the following:

- Data were collected by the Cobra Dane/Cobra Judy sensors.
- SRMP's two flights—November 1987 and October 1988—have collected data on targets of interest.

6.1.5.4 Future Plans

The AOA/AST will use targets of opportunity to collect exoatmospheric signature data, and demonstrate acquisition and tracking functions. Two SRMP flights have occurred to date. Two flights are planned to occur each year over a period of several years. Many of the phenomenology experiments to support BSTS have yet to be performed. Plans call for execution of TCE, VUE, IBSS, CIRRIS, Starlab, Delta Star, and Excede.

Several experiments are planned to gather additional data in support of BSTS. Successful BSTS operations depend on adequate knowledge of plume (solid and liquid) and fuel vent signatures, as well as earth, earthlimb, and nuclear burst backgrounds.

Plume data will be acquired by TCE, VUE, Starlab, IBSS, Delta Star, LACE, and the Malabar/AMOS facilities (ongoing). Fuel release signature data will be collected from TCE and chemical release experiments associated with the IBSS experiment and Delta Star.

CIRRIS 1A, IBSS, Starlab, TCE, and VUE collect data on natural backgrounds relevant to BSTS. Excede III will assist the development and validation of nuclear weapon codes. MSX builds on a technology legacy and will serve to reduce the technology risk of Phase I MCS elements.

6.1.6 Discrimination Technology

A fundamental (and common) system-level need that confronts all of the sensors in the SDS is their capability to discriminate between the lethal and benign targets deployed from Soviet ICBMs and SLBMs, as well as the fragments and the debris, in order to identify the lethal RVs. The discrimination function is of primary importance because the number of intercepts available to the defense is limited and the potential for creating benign targets (decoys, etc.) is large.

The passive sensors (BSTS, SSTS, and GSTS) and active sensor (GBR) discussed in Section 5 play a significant role in providing the discrimination performance required for the Phase I SDS. Laser Radar technology and the interactive techniques will play a key role in maintaining the effectiveness of the SDS as the threat continues to evolve.

6.1.6.1 Technology Goals

The primary goal of the Discrimination Technology project is to seek and exploit signatures of the ensemble of objects in the threat cloud released by a ballistic missile. The need is to uniquely identify the objects as lethal or benign. It is an effort that must be sustained to maintain SDS mission capability in face of an increasing level of sophistication in the Soviet response to the United States defense. To achieve this goal this project must maintain an active interface with the Phenomenology Project, the technology base, and the SDS element development.

6.1.6.2 Project Description

There are three types of sensors for making discrimination measurements during missile boost and post-boost, midcourse, and high endoatmospheric phases. These sensors are referred to as being passive, active, or interactive. Passive sensors measure the UV, visible, and IR energy received from targets, and allow determination of plume booster and PBV characteristics.

Active sensors (microwave and laser radars) transmit small amounts of energy to the targets and a portion of this energy is scattered back to the sensor. This type of sensor has two important advantages. First, active sensors allow measurement of targets which might otherwise be hidden (e.g., their thermal characteristics match that of the background and produce no contrast). Second, these sensors allow control of the time, rate, and form at which energy arrives, thus allowing measurement of target parameters such as range and velocity. Details on the technology base efforts in passive, active and interactive sensors are found in Sections 6.1.1 through 6.1.3.

The last category of sensor discrimination performance is called interactive. These sensors consist of passive and active sensors coupled with a high energy active source. The source could be a laser, like the SBL. The source interrogates the target by focusing its energy on it, at a level sufficient to perturb it in some predetermined manner. These changes are then detected by the active or passive sensor in the interactive system.

Finally, in discrimination using radar, the foremost need for a GBR is the discrimination of advanced penetration aids. Discrimination is being approached through target motion studies and data analysis for the development of new discrimination techniques. The GBR experiment will help to resolve discrimination issues and guide the development of effective new algorithms. Related efforts are described in more detail in Section 6.1.5.

6.1.6.3 Accomplishments

Several potential discrimination techniques have been identified for the boost and post-boost, midcourse, and high endoatmospheric layers. Techniques relating to endoatmospheric phase discrimination were field tested using the Reentry Designation and Discrimination System. Similar tests and demonstrations remain to be performed for high endoatmospheric, midcourse, and boost layer algorithms. A limited set of end tests began recently using the real-time imaging and discrimination test bed.

The GBR-X discrimination algorithm development will provide real-time discrimination against multiple penetration aids in the midcourse and high endoatmospheric layers. Once developed, the algorithms will be tested using the AOA before being provided to GSTS and SSTS system engineers.

6.1.6.4 Future Plans

Real-time tests will be performed for six radar algorithms, and preparations will begin for real-time testing of three passive LWIR algorithms. However, to test these algorithms effectively, careful planning must be undertaken to assess what will be learned in the phenomenology efforts from the data collected; what special targets need to be flown; and what types of sensors are required for data collection. Such in-depth planning is currently being undertaken and will continue.

It is unlikely that all discrimination techniques and countermeasures have been identified. Significant techniques relating to passive sensors operating at several wavelengths are evolving. Architectures for combining real-time discrimination algorithms remain to be accomplished. In the past, new discrimination techniques were found as new target observations were made. This is likely to occur as new data processing techniques are developed, which take advantage of advances in machine intelligence and neural network hardware.

A real-time imaging and discrimination test bed has been established for testing and evaluating real-time algorithms. Passive LWIR data obtained by Cobra Eye for targets will be recorded and used for algorithm evaluation. Preparations for real-time testing using passive data are also under way.

Section 6.2

CC/SOIF Technology

6.2 CC/SOIF Technology

This section discusses CC/SOIF technology goals and projects and describes their accomplishments and future plans.

6.2.1 Technology Goals

The goal of this technology base effort is to develop the technology required to support a responsible, reliable, survivable, and cost-effective Command Center/System Operation and Integration Functions program. The program seeks to satisfy technology needs in five areas: algorithms, software engineering, processors, network concepts, and communications. These technology efforts must provide the required system properties of reliability, testability, durability/survivability, robustness, security, component producibility, and availability. Figure 6.2-1 identifies the types of activities involved in pursuing these five technology areas. The individual objectives required to achieve the overall goal is described below:

- Algorithms—Analysis and research leading to development of algorithms that are responsive to the CC/SOIF architecture requirements developed in an appropriate threat environment.
- Software Engineering—Analysis, evaluation, and research leading to the creation of secure SDI software development environments that provide the capability to produce software with the requisite productivity and quality. A near-term capability is needed to support both the CC/SOIF experimental systems effort and a potential defensive system.
- Processors—Analysis and research leading to development of information processing technology, devices, and subsystems that are secure, high-performance, fault-tolerant, space qualified, and hardened to withstand hostile environments. This task also includes the development of operating systems, executive and file management software, and firmware that is indigenous to the local processing environment. This task area responds to the requirements to implement battle management algorithms and C^3 networks.
- Network Concepts—Analysis and research leading to the development of CC/SOIF networks responsive to the architecture requirements developed in the CC/SOIF Experimental Systems effort.
- Communications—Analysis and research leading to and including the development of communications technology, devices, and subsystems that are secure and robust, which will support the multimode/multimedia network data rates required for the several alternative defense architectures and their evaluations and variations. This task also includes the development of embedded software and hardware indigenous to the communications environment.

Figure 6.2-1
CC/SOIF Technology Base Activities

<table>
<tr>
<td>Algorithms
• Track initiation
• Discrimination
• Weapon target assignment
• Data fusion
• Kill assessment
• Situation assessment
• System reconfiguration
• Defense tactics
• Battle planning</td>
<td>Software Engineering
• Software engineering and development environment
• Producibility
• Security
• Robustness
• Testability
• Survivability
• Evolvability</td>
</tr>
<tr>
<td>Processors
• Security
• Fault tolerance
• Reliability
• High throughput rates
• Large memory
• Power/size/weight</td>
<td>Network Concepts
• Network control and management
• Message routing
• Multiple media
• Protocol engineering
• Network reconfiguration
• Switching technology
• Security
• Reliability</td>
</tr>
<tr>
<td colspan="2">Communications Technology
• Robustness
• Security
• Data rates
• Laser links
• RF links</td>
</tr>
</table>

6.2.2 Project Description

The technology projects are designed to develop the advanced technologies needed by the CC/SOIF system. Six critical CC/SOIF technologies are being pursued to resolve the key technology issues. Until an FSD decision occurs, integrated tests must be performed by emulation/simulation. Ongoing activities are discussed in the remainder of this section.

Algorithm Technology

The SDIO vigorously pursues algorithm technology. Because of the unique inputs, operational objectives, and the environment of SDS, tested and proven algorithms are not likely to be developed outside the SDI community. Specific attention is being given to algorithms peculiar to the SDS layered defense, including those for interceptor-target assignment, threat track initiation and maintenance, and multisensor discrimination. The EV88 program, which provides high-fidelity models for architecture evaluation, has incorporated algorithms for the midcourse and terminal layers of the SDS.

There has been activity in the area of multisensor trades and correlation as part of a program effort to develop advanced algorithmic approaches. There is significant work in progress for the Weapon Target Assignment (WTA) program, including advanced algorithm development, test, and evaluation. Finally, the Algorithmic Architectures program is planned to begin the design and development of robust algorithms matched to advanced parallel processing architectures so as to achieve real-time performance of critical CC/SOIF functions.

Software Engineering

The volume of software needed for SDS will be larger than any developed to date. Its scope will be broad, spanning the spectrum of software technologies. It will pose unprecedented requirements for reliability, maintainability, adaptability, and performance. The SDIO realizes that it must create and foster an acquisition and management environment that encourages, promotes, and rewards the use of modern software engineering practices. To this end, the SDS Software Policy provides guidance on how to use appropriate software engineering practices for the development of all mission-critical, full-scale development SDS software; this guidance is responsive to the Report of the Defense Science Board Task Force on Military Software.

The SDS Software Policy includes the following specific requirements:

- The development of the Ada programming language which was specifically created to support "programming-in-the-large."
- The use of design and development tools and environments that provide rigor of notation and analysis.
- The use of a prototyping approach to software development for evolving systems like the SDS. The principle advocated (build a little, test a little) provides the critical feedback loop into requirements specification.
- An SDS Security Policy to be developed by the National Security Agency.
- Potentially reusable software.
- Portable software.
- The use of data rights concepts of the Federal Acquisition Regulation Part 27, 1987, or the model standard Data Rights in Software clause given in the Report of the Defense Science Board Task Force on Military Software.
- Testing strategies using state-of-the-art techniques throughout the acquisition cycle.

An SDS Software Center of Excellence (SCOE) is being established at the National Test Facility in Colorado Springs to support the large-scale integration of software for the SDS. The Center will provide configuration control and ensure efficient production of trusted, high-confidence, mission-critical software throughout the SDS life cycle. A software laboratory is currently being developed as an integrated software system tool to support the SDS in achieving this capability. The SCOE will perform the following functions:

- Software education and training to ensure consistency of SDS-related software acquisition, design, development, and testing efforts
- Working examples of software engineering and support environments that meet the interface requirements of the SDIO
- Development and operation of a software library that will become the focal point for the identification, storage, and retrieval of software designs, documentation, and codes
- Programmatic support through consultation and special assistance with technological problems encountered by the elements.

Because the SDIO has a significant investment in software technology, it is working with DOD and other government agencies such as the Ada Joint Program Office (AJPO), NSA, DARPA, Software Engineering Institute (SEI), Software Technology for Adaptable, Reliable Systems (STARS) Program Office, and NASA to coordinate and exploit their efforts in software engineering environments and software management techniques.

In summary, SDIO has, over the past year, established a software policy emphasizing good software engineering practices, established a software center to enforce standards and policy and encourage modern software development, and identified key software technology thrusts that will help improve the state of the practice as well as the state of the art in software development.

Processor Technology

Processor requirements for SDS are being addressed through a variety of ongoing programs in DOD, through which SDIO expects to gain leverage. For example, SDIO is a major cosponsor of the DARPA Strategic Computing Program and maintains a strong interface with their ongoing program to develop VHSIC technology processors.

CC/SOIF projects will draw on device technology research supported by the SDIO Sensor Directorate. Included are hardened complementary metallic oxide semiconductors, gallium arsenide (GaAs) technology, and silicon-on-insulator hardware. Programs in the SOIF processor area are under way to attain the necessary characteristics in the area of operating speed, reliability, fault tolerance, and memory. The CC/SOIF technology project supports work in processor architecture while emphasizing scalability. The processor technology development is further complicated by the survivability requirement of radiation hardness.

Projects in this area are designed to progress from present technology to survivable and space qualifiable processors operating at 100 MIPS, using GaAs technology for speed and radiation survivability.

Networking Technology

Communications networking technology is being developed which provides for survivability, adaptability, security, high bandwidths, multimedia, and fault tolerance. The current technology development activity is to develop network control algorithms, message routing algorithms, and network processing equipment. Major programs in networking include those for defining security requirements, evaluating bandwidth requirements, and routing and studying network packet switching.

Communications Technology

Communications needs for SDS are particularly critical in the space-to-space area while other links are being addressed in various DOD programs. Both laser technology and RF technology have seen important recent progress arising from continuing SDIO-sponsored research. Agile beam lasers and agile beam phased arrays are among the most active research studies. The trends have generated strong encouragement that SDS requirements can be met in a timely fashion. (See Figure 6.2-2.)

6.2.3 Accomplishments

The SDIO is working with NSA, the STARS Program Office, and the SEI to develop a life-cycle model for the incorporation of security issues in a system; a trusted operating system, Ada compiler, and run-time environment; and techniques to verify Ada software.

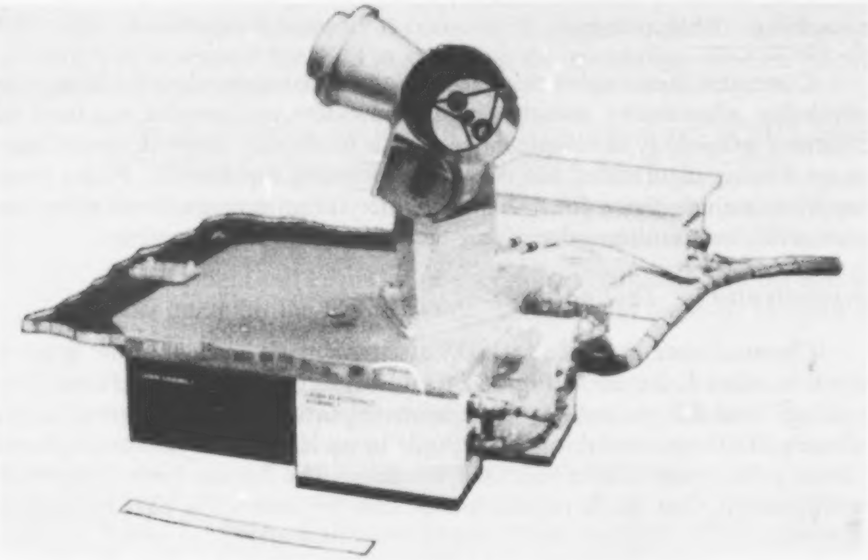
The SDIO is cofunding efforts in distributed operating systems with DARPA and RADC. These efforts are directed at meeting the wide range of distributed and real-time operating system requirements to support the development and testing of the SDS. Included are the development of heterogeneous networks of computers and the development of minimal real-time kernels for operational use on space-based platforms of the SDS.

The SDIO is funding university work that addresses the issues of programming parallel architectures. This work includes Linda, a system that supports programming a shared-memory multiprocessor, and Crystal, a system that supports programming a wide variety of unique parallel architectures using a functional programming language.

The development of algorithms that perform well on parallel architectures is another important issue for SDI. Such work is proceeding at Argonne National Labs, Los Alamos National Labs, RADC, and Strategic Defense Command (SDC).

The SDIO is working with the Ada Joint Program Office to adapt Ada to its unique requirements. SDIO-specific needs are being considered in the Ada 9x revision

Figure 6.2-2
Laser Crosslink



now under way. Research is proceeding to address the technological problems involved in the development of distributed real-time systems in Ada.

The SDIO is participating in the ONR Real-Time Initiative to address the unique requirements of specification, design, execution support, and testing of real-time software. The SDIO is supporting software engineering environment work with DARPA for the SDS. These efforts are aimed at meeting both near- and long-term requirements of the SDS. The results will be fed into the SDS Software Center.

6.2.4 Future Plans

Significant activity in developing the critical technology areas is expected in the near future. Technology areas to be developed include the following:

- Secure communication architectures and test beds (COMSEC)
- High-power laser cross-link components, including diodes and optical receivers
- High speed GaAs processors
- Advanced algorithms for midcourse battle management
- Fault-tolerant, high-speed distributed networks for sensor processing and battle management.

Section 6.3

Interceptor Technology

6.3 Interceptor Technology

Current projects applicable to both strategic and tactical weapon systems in advanced weapons technology base address four primary areas: kinetic energy (hit to kill) interceptor, components, validation capabilities, and alternative launch mechanisms. These technology projects are designed to support full-scale development decisions for Phase I and follow-on SDS elements (i.e., SBI, ERIS as it is now evolving into the ground-based interceptor [GBI], HEDI, Arrow, and ERINT), and the hypervelocity gun (HVG). Kinetic kill vehicles (KKVs) are propelled by either a chemical booster or an HVG to within homing range of threat boosters, post-boost vehicles (PBVs), and reentry vehicles (RVs).

6.3.1 Technology Goals

There are several critical technology goals common to all interceptor technology development. High probability of kill is desired for each interceptor, so that the total number of interceptors may be minimized at each system level. Low-weight interceptors and launchers are necessary to achieve low life-cycle costs because transportation is such a large part of the cost drivers (e.g., space launch and mobile or fixed GBI systems). Similarly, long service life is desired to keep replacement/maintenance cost down. Advanced interceptor technology components are integrated into lightweight exoatmospheric projectiles (LEAP) and endoatmospheric projectiles (D-2) for validation and characterization. Finally, for interceptors and hypervelocity launchers to be deployable, they must fit into a larger communications scheme for fire control and health status. They must also meet the survivability requirements and be capable of meeting high production rates.

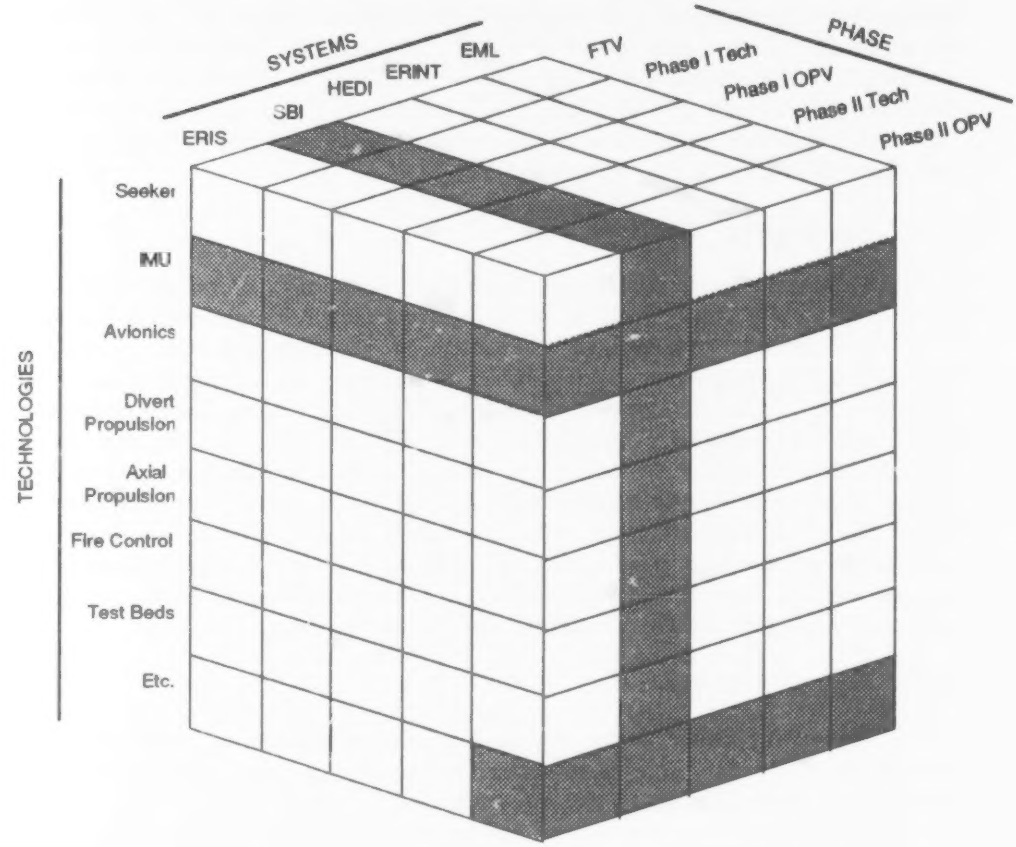
6.3.2 Project Description

This section describes the organization of cross-linked interceptor technologies, component technology projects, integrated technology projects, validation technology projects, and alternative launch technology project.

Cross-Linked Technologies Organization

The technology base is organized as a three-dimensional matrix (Figure 6.3-1). One axis is time dependent, beginning with early experimental interceptors and proceeding through phased deployment designs. Another axis has components, the integration of components, and the validation of all hardware. The final axis spans the interceptor elements and includes theater missile defense and hypervelocity guns. This organization allows for technology maturity in individual generic technologies to be correlated with the requirements of each interceptor element. To avoid duplication, each generic technology is programmed to maximize funding in a "leader/follower" technology base. The technology under the lead interceptor technology base, where the payoff to that interceptor is the highest, receives the majority of the funding. Follower technology bases are established only to receive the developed technology and amend it to conform to the particular interceptor application.

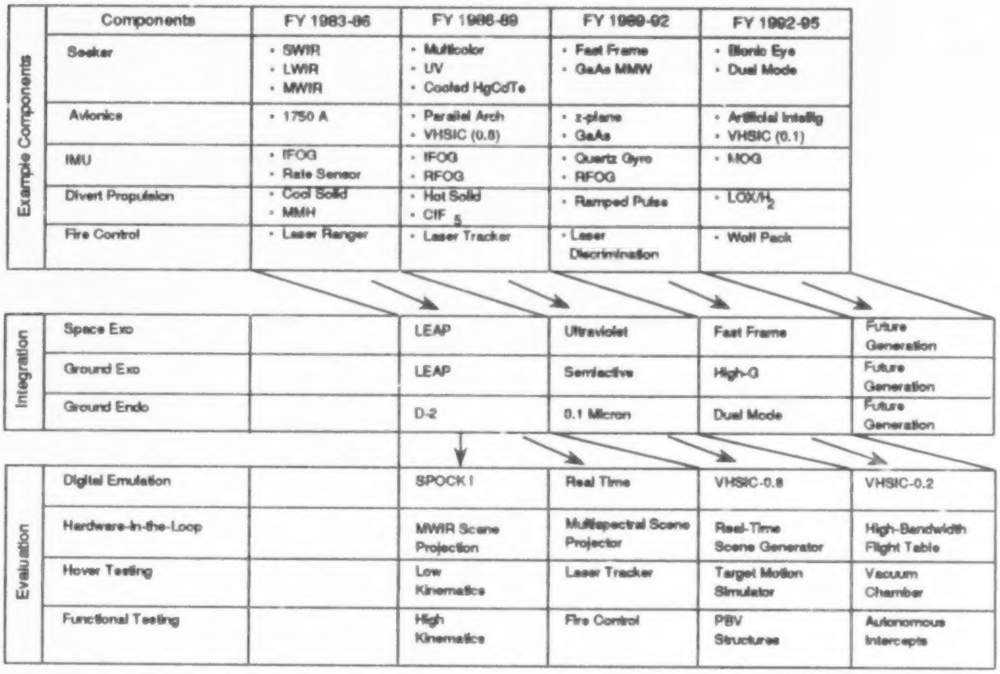
Figure 6.3-1
Cross-Linked Technology Relationships


SYSTEMS
ERIS
SBI
HEDI
ERINT
EML
FTV
PHASE
Phase I Tech
Phase I OPV
Phase II Tech
Phase II OPV
TECHNOLOGIES
Seeker
IMU
Avionics
Divert Propulsion
Axial Propulsion
Fire Control
Test Beds
Etc.

Technologies will achieve breakthroughs at varying rates, requiring these time-phased groupings to be evaluated for their potential payoffs to the SDS elements. Hence, as shown in Figure 6.3-2, mature 1983–86 technologies were integrated into the first LEAP programs to be evaluated using the facilities designated. This process develops mature technology for the SDS elements.

Interceptor technology projects are organized in four categories: component projects, integration projects, validation technology projects, and alternative launcher technology.

Figure 6.3-2
Technology Flow for ERIS, HEDI, SBI, ERINT, HVG



	Components	FY 1983-86	FY 1986-89	FY 1989-92	FY 1992-95	
Example Components	Seeker	• SWIR • LWIR • MWIR	• Multicolor • UV • Cooled HgCdTe	• Fast Frame • GaAs MMW	• Bionic Eye • Dual Mode	
	Avionics	• 1750 A	• Parallel Arch • VHSIC (0.8)	• z-plane • GaAs	• Artificial Intellig • VHSIC (0.1)	
	IMU	• IFOG • Rate Sensor	• IFOG • RFOG	• Quartz Gyro • RFOG	• MOG	
	Divert Propulsion	• Cool Solid • MMH	• Hot Solid • ClF_5	• Ramped Pulse	• LOX/H_2	
	Fire Control	• Laser Ranger	• Laser Tracker	• Laser Discrimination	• Wolf Pack	
Integration	Space Exo		LEAP	Ultraviolet	Fast Frame	Future Generation
	Ground Exo		LEAP	Semiactive	High-G	Future Generation
	Ground Endo		D-2	0.1 Micron	Dual Mode	Future Generation
Evaluation	Digital Emulation		SPOCK I	Real Time	VHSIC-0.8	VHSIC-0.2
	Hardware-in-the-Loop		MWIR Scene Projection	Multispectral Scene Projector	Real-Time Scene Generator	High-Bandwidth Flight Table
	Hover Testing		Low Kinematics	Laser Tracker	Target Motion Simulator	Vacuum Chamber
	Functional Testing		High Kinematics	Fire Control	PBV Structures	Autonomous Intercepts

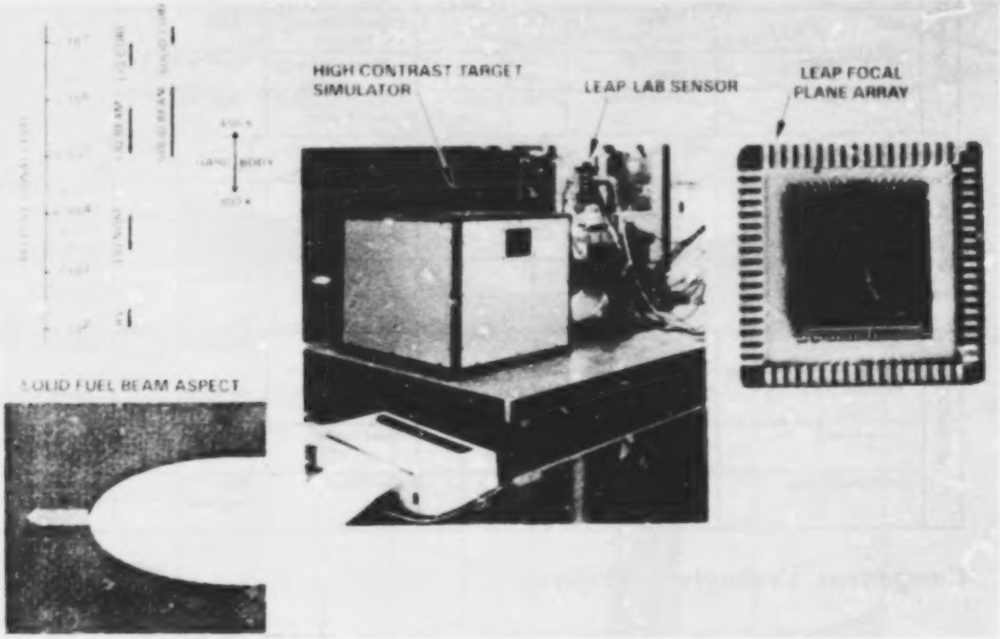
Component Technology Projects

Component technology projects include seeker technology, avionics technology, IMU technology, divert control, rocket axial propulsion technology, and fire control technology.

Seeker Technology Projects. The seeker represents the "eyes" of the interceptor. Seeker technologies vary with the interceptor environment and the threat characteristics, although passive infrared (IR) and active millimeter wave (MMW) seekers are the most common. Typically, long-wavelength infrared (LWIR) seekers are used for targets with low IR signatures (such as RVs), while medium-wavelength infrared (MWIR) seekers are used against boosters with hot plumes. Short-wavelength infrared (SWIR) and MMW seekers are used in the terminal phase against RVs entering the atmosphere. The seeker shown (Figure 6.3-3) is being developed as part of the LEAP program. It uses a 128 x 128 pixel size, HgCdTe staring focal plane array.

One of the most critical seeker issues is the achievement of long acquisition ranges. Long-range interceptors allow relaxed handover accuracy requirements and also result in benefits to the interceptor design: more time for divert maneuvers, reduced field of view, and smaller focal plane array. Other related performance issues include high resolution, image stabilization, hardbody imaging, and the ability to discriminate closely spaced objects (CSOs) in midcourse. In addition to high performance, seekers must be hardened to operate in severe nuclear environments and must be capable of high-rate production. Microchip and lithographic production technologies allow designs with performance far beyond conventional weapon systems to be implemented.

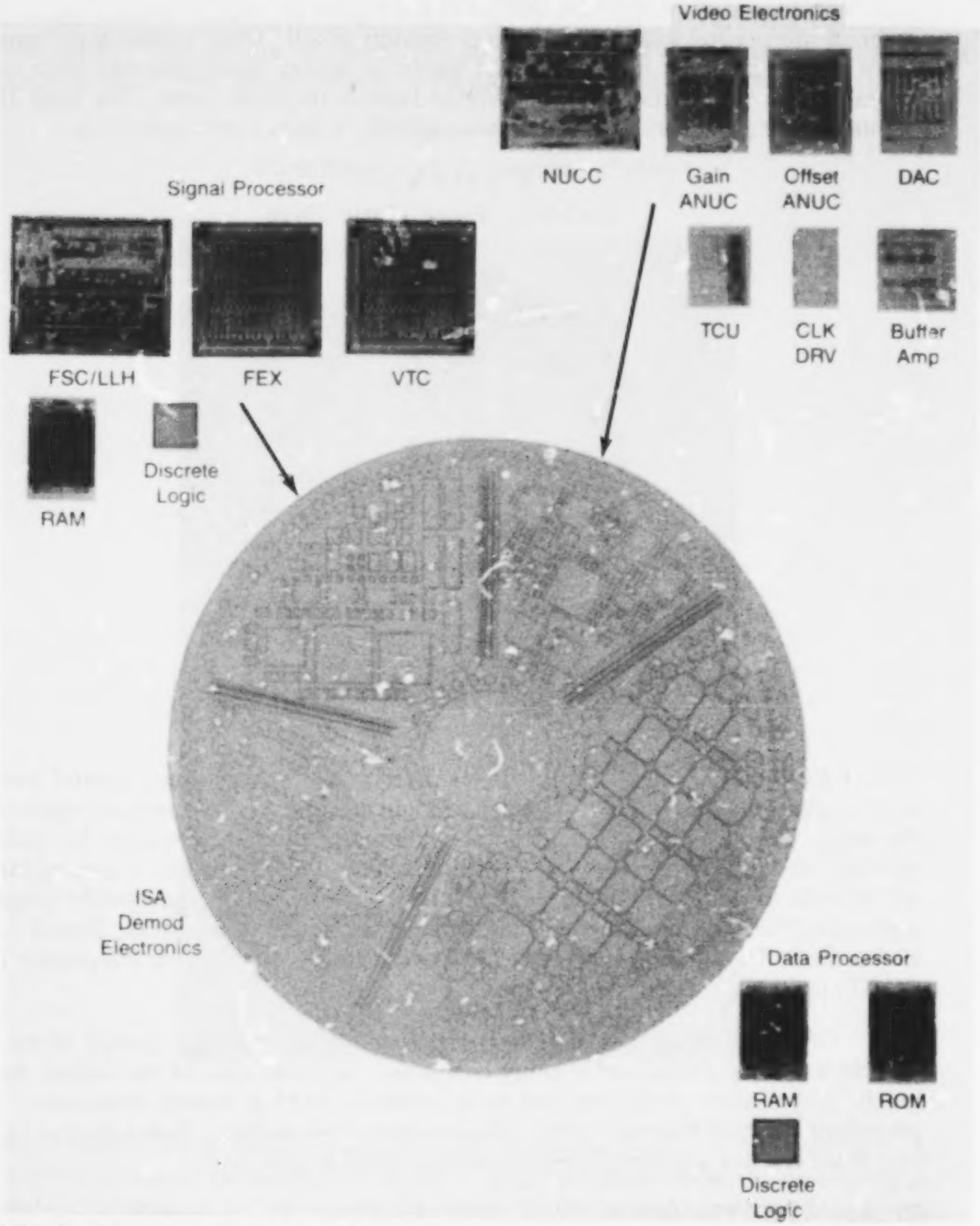
Figure 6.3-3
LEAP 128 x 128 Seeker



Avionics Technology Projects. Avionics components represent the "brains" of the interceptor. Avionics functions include image processing and body motion compensation. Image processing is the interpretation of electrical signals from the focal plane array. The electrical signals contain information on position and intensity of the image on the FPA. The processors also stabilize the image by electronically compensating for motion induced by motor firings as the projectile homes in on its target. Wafer-scale integration has enabled tremendous reduction in processor size while providing similar advances in algorithm throughput. The LEAP processor shown in Figure 6.3-4 includes a signal processor, video electronics, inertial sensor assembly (ISA) demodulation electronics, and data processor.

Avionics technology development will result in system-level benefits by reducing the handover accuracy requirements from external sensors and improving the probability of kill. Development efforts must address the need for high processing throughput and algorithms that can handle aim-point selection and CSO discrimination. In addition to the high-performance characteristics, the avionics processors and memory must be capable of operating in severe nuclear environments.

Figure 6.3-4
LEAP Wafer-Scale Integration

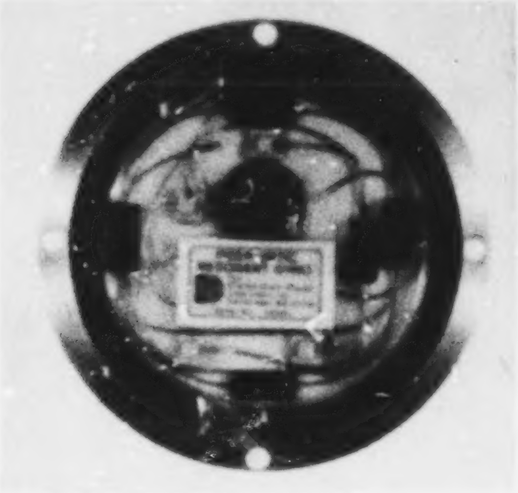

Video Electronics
NUCC
Gain ANUC
Offset ANUC
DAC
TCU
CLK DRV
Buffer Amp
Signal Processor
FSC/LLH
FEX
VTC
RAM
Discrete Logic
ISA Demod Electronics
Data Processor
RAM
ROM
Discrete Logic

IMU Technology Projects. IMUs measure change in the interceptor's direction and speed and provide this information to the guidance computers for updates of the interceptor position. An IMU typically consists of several gyroscopes and

best copy available

accelerometers. Gyroscopes measure change in direction and accelerometers measure change in velocity. This information is critical for hit-to-kill intercepts. Interceptors with high accuracy/low drift rate IMUs will not require as much guidance support from external sources and will have a higher probability of kill. Other system-level benefits from IMU technology include relaxed handover basket constraints and more rapid initialization of interceptors for shorter launch response time. The lead IMU technology, the resonant fiber optic gyro (RFOG), is shown in Figure 6.3-5.

Figure 6.3-5
Resonant Fiber Optic Gyro



Divert Control. Divert control includes divert motors and attitude control motors used to adjust the kill vehicle's direction of flight and orientation to ensure impact with the target. Technologies in divert control will impact system requirements for tracking accuracy and discrimination because the interceptor will be capable of making larger adjustments in trajectory during end-game homing. In addition, lightweight thrusters and more efficient propellants will result in lighter weight interceptors. Figure 5.3-7 shows divert firing during test of a hover vehicle at the Kinetic Hover Interceptor Test (KHIT) facility at Edwards AFB, California.

Critical development issues include control of the center-of-gravity of the kill vehicle while the propellant is being consumed, response time of the valves, thrust levels, kill vehicle structures that will withstand high g lateral maneuvers, and propellant selection that minimizes contamination of the seekers. Both solid and liquid propellant systems are being developed to meet these requirements.

Rocket Axial Propulsion Technology Projects. The interceptor axial motor provides acceleration toward the target. Typically, an interceptor will have at least two axial motors; each will separate from the kill vehicle after completing its burn. Development of motors with high thrust and fast-burn characteristics will enable the deployment of kinetic energy interceptor systems that will require fewer interceptors and are able to respond to changing threats. Lightweight propulsion subsystems will not only benefit space-based interceptors, but will lower the cost of ground-based interceptors. The picture (Figure 6.3-6) shown is that of a strap-down firing of a booster with fast-burn gel propellant for the ground-based interceptor project.

Figure 6.3-6
Fast-Burn Gel Propellant Firing

Fire Control Technology Projects. Fire control technologies are important for the effective use of interceptors. The fire control function includes the processing and handover of external sensor data for determination of interceptor-to-target assignments, midcourse guidance updates for interceptors, target discrimination, and kill assessment. Fire control issues to be addressed include pointing and tracking accuracy for laser and radar trackers, algorithms for target assignments and discrimination, data processing of large numbers of objects within short timelines, and guidance update frequency and associated data rates. Several laser and radar tracker technologies are being pursued with the goal of developing a lightweight, reliable fire control system that can handle large numbers of objects within the field of regard of the host vehicle.

Integration Technology Projects

This project stresses the most difficult engineering task in interceptor technology, i.e., integration. Once advanced components have matured, they can be integrated into interceptor kill vehicles. The goal is to produce integrated kinetic kill vehicles that are miniaturized and lightweight. The project includes efforts ranging from concept definition and analytical assessment through simulations to advanced technology developments using hybrid units. Technical activity centers on the development of low-cost, miniature kill vehicles that can be launched either chemically or with a hypervelocity gun. The project includes the integration of seekers, avionics, guidance and fire control, propulsion, and structures. The guidance control will include IMUs and electronics that have the lightest weight and lowest cost that technological advances can achieve. A propulsion and structures technology project includes lightweight, high-strength materials for all interceptor applications. The tremendous advances in the state of the art achieved with respect to conventional integrated vehicles (D-2) is shown in Figure 6.3-7.

Validation Technology Projects

To support fully the project offices designing the interceptors, complete interceptor simulations are constructed, initially using physical principles and end-to-end intercept scenarios. Typically, these simulations have few nonlinear effects and a low level of detail. As component designs are built and integrated, there arises a need to validate the simulation against the nonlinearity of nature. This will allow the design process to begin anew with higher confidence on the predicted performance of the interceptor. Because the interceptor technologies are so advanced, the state of the art for evaluating their capability needs improvement. This is accomplished in digital emulation, hover testing, hardware-in-the-loop demonstrations, and flight demonstrations. The pieces of an interceptor that would require testing are shown in Figure 6.3-8.

Digital Emulation Technology Projects. Current efforts are under way to develop real-time digital emulation computers and hardware-validated software to provide real-time, highly detailed emulation of the interceptor performance in an end-to-end, one-on-one engagement. This will provide the program offices with extremely capable redesign tools. Additionally, this technology will provide spinoffs to the data processing needs of sensors and interceptors. This equipment is located in the Kinetic Energy Digital Emulation Center (KDEC) in Huntsville, Alabama. This facility will also store the test results of interceptor performance and have the master simulation which has been validated through hardware testing.

Figure 6.3-7
Integration Projectiles

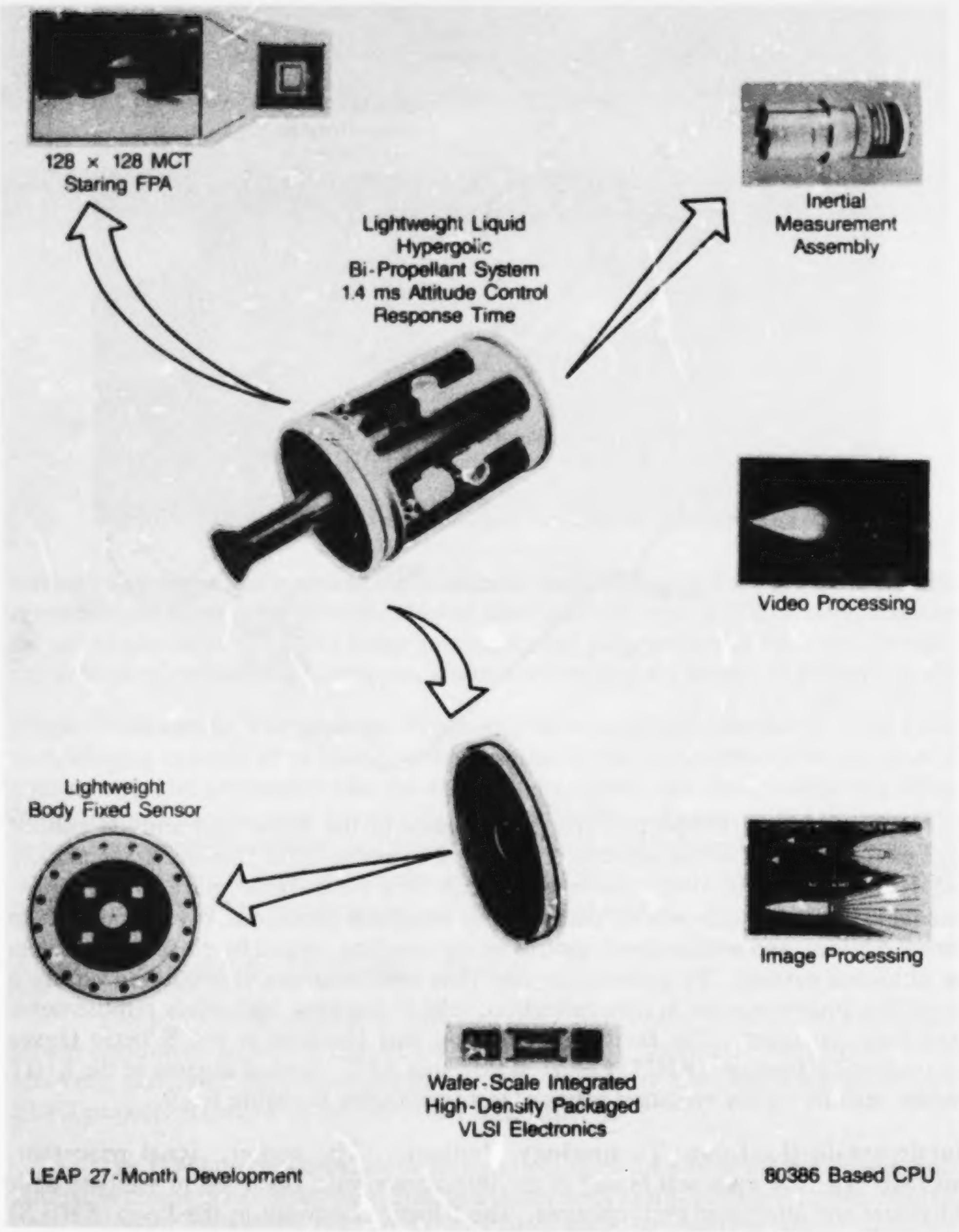
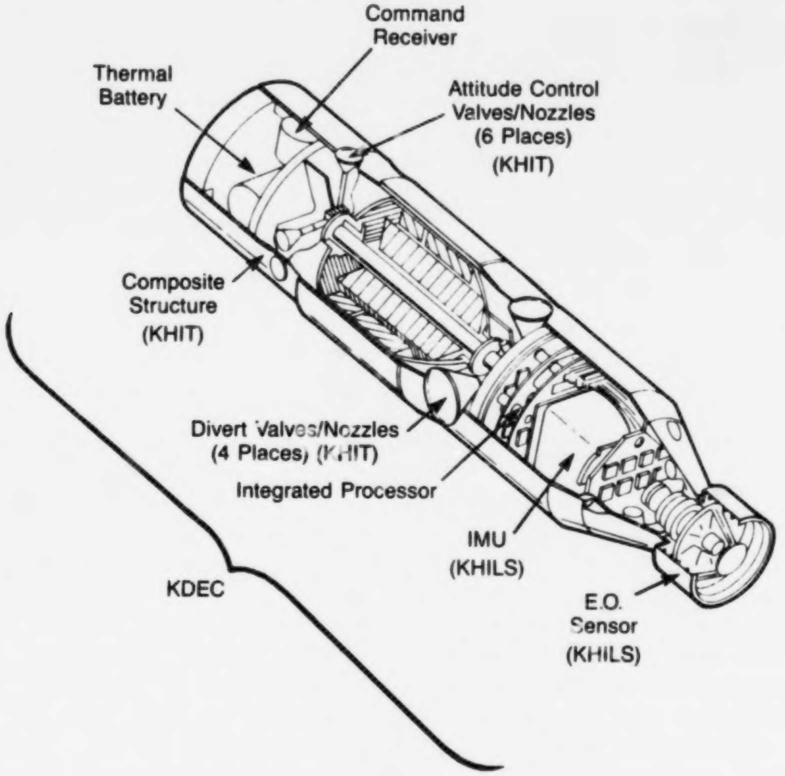

128 × 128 MCT
Staring FPA
Lightweight Liquid
Hypergolic
Bi-Propellant System
1.4 ms Attitude Control
Response Time
Inertial
Measurement
Assembly
Video Processing
Lightweight
Body Fixed Sensor
Image Processing
Wafer-Scale Integrated
High-Density Packaged
VLSI Electronics
LEAP 27-Month Development
80386 Based CPU

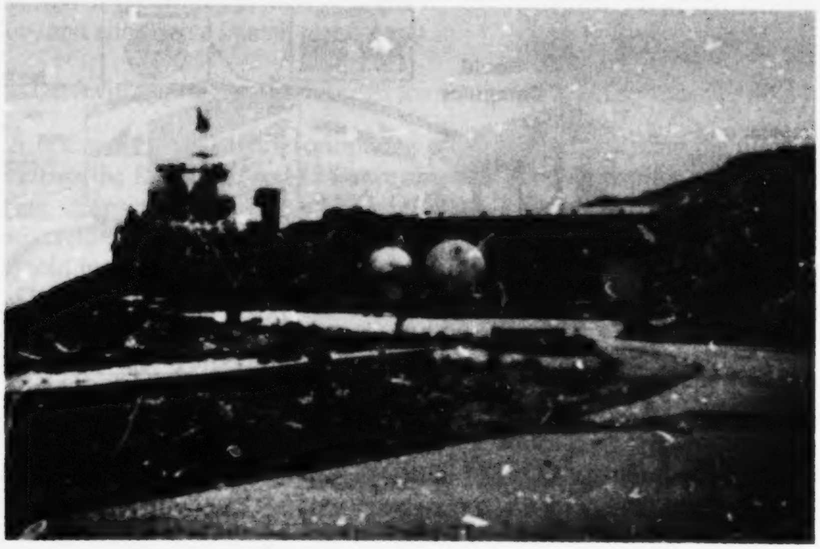
Figure 6.3-8
Interceptor Validation


Command Receiver
Thermal Battery
Attitude Control Valves/Nozzles (6 Places) (KHIT)
Composite Structure (KHIT)
Divert Valves/Nozzles (4 Places) (KHIT)
Integrated Processor
IMU (KHILS)
E.O. Sensor (KHILS)
KDEC

Hover Technology Projects. The performance of the divert and attitude control engines (i.e., the legs of the interceptor) needs to be assessed for stability kinematically and dynamically. For about one-tenth the cost of a comparable space flight, a low-kinematic hover test can provide data on body structural vibrations, divert and attitude control engines, and seeker-divert control motor coupling caused by closing the loop in the guidance system. To process the real-time nonlinearities encountered during a hover test, improvements in data collection, vehicle tracking, and safety requirements have been initiated. The facility performing this function is the Kinetic Hover Interceptor Technology (KHIT) Center at Edwards AFB. Several aspects of the KHIT facility perfoming the on-target series of tests are shown in Figure 6.3-9.

Hardware-in-the-Loop Technology Projects. The seeker, signal processor, and IMU (i.e., the eyes and brain) of the interceptor must be tested to validate their individual and integrated performances. The Kinetic Hardware-in-the-Loop (KHILS) emulator facility at Eglin AFB, Florida, is equipped with advanced infrared interceptor

Figure 6.3-9
KHIT Facility, Edwards AFB



testing capability. The speed of the electronic operations and the wave band of seeker operations were stressing the capability of other national tactical HWIL sites, and hence the development of advanced scene generation and projection was initiated. Several of the aspects of performing interceptor shakedown testing are shown in Figure 6.3-10.

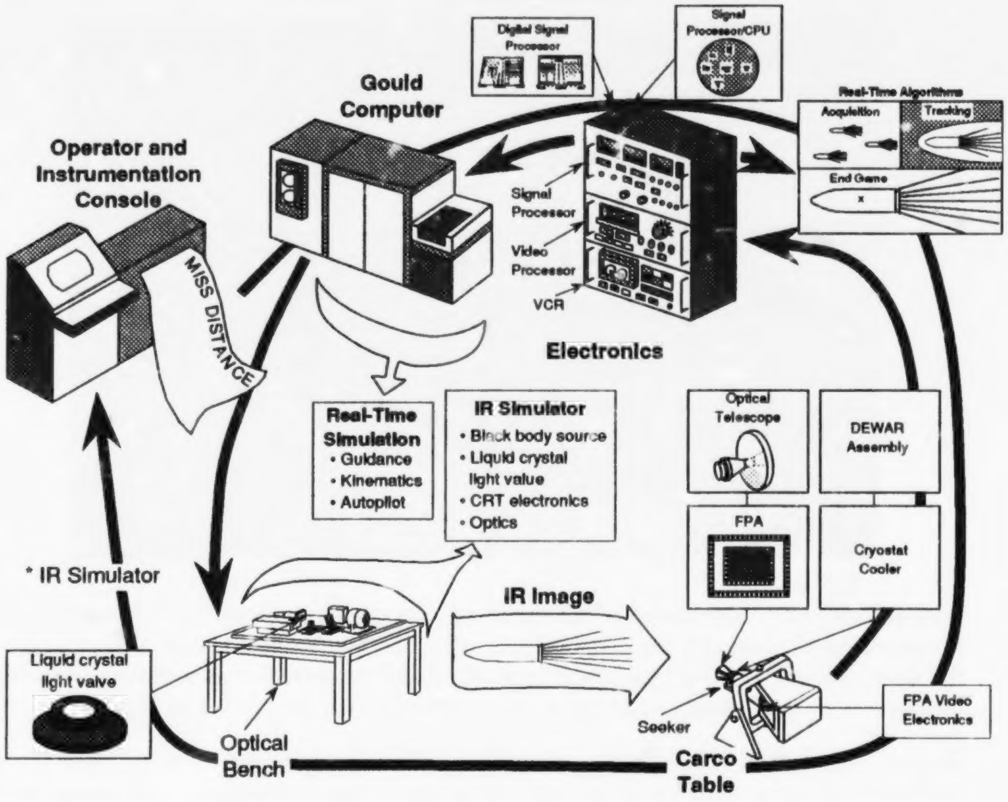
Flight Validation Technology Projects. The final requirement to fully certify technologies capable of inclusion in the baseline of the interceptors is to integrate the components and interceptor into the environment where they are intended to perform. Normally this can be done only by flight qualification. Advances in miniaturization technologies and instrument qualifications have allowed tremendous reductions in the cost of full flight verification. Standardization of test payload carriers and test boosters will further reduce the recurring costs of such crucial testing.

Alternative Launch Technology Project

The key technical areas of interest for the hypervelocity gun are prime power, power conditioning, barrel life, efficiency, scalability, thermal management, energy recovery, and barrel slewing requirements. These priority areas are being addressed in SDIO projects managed by the Air Force and Army.

The HVG project depends on key technologies for power system development. Although progress has been very rapid at a technology component level, little effort has been extended toward the development of large-scale, lightweight power supplies for the HVG which are necessary for the development of actual systems.

Figure 6.3-10
KHIL Testing


Digital Signal Processor
Signal Processor/CPU
Gould Computer
Real-Time Algorithms
Acquisition
Tracking
End Game
x
Operator and Instrumentation Console
MISS DISTANCE
Signal Processor
Video Processor
VCR
Electronics
Real-Time Simulation
• Guidance
• Kinematics
• Autopilot
IR Simulator
• Black body source
• Liquid crystal light value
• CRT electronics
• Optics
Optical Telescope
DEWAR Assembly
FPA
Cryostat Cooler
* IR Simulator
IR Image
Liquid crystal light valve
Seeker
FPA Video Electronics
Optical Bench
Carco Table

All HVG activities are presently in the technology development phase which addresses feasibility. However, progress has been rapid and guns already exist which have muzzle energies rivaling the largest main battle tank guns.

The HVG project will perform cooperative development activities with the integrated technologies area in order to develop, integrate, demonstrate, and validate the technologies required for both ground- and space-based HVG elements of an SDS. This includes the launcher, integrated endoatmospheric projectile, exoatmospheric projectile, and fire control systems. These subsystems will be validated through program testing of digital emulation; hardware-in-the-loop, controlled ground hover testing; launcher firings; rapid-fire testing; both endo- and exoatmospheric free-flight testing; and piece part, subsystem, and full projectile high g and magnetic field testing.

6.3.3 Accomplishments

This section describes accomplishments in component technology such as avionics, IMU technology, divert control, rocket axial propulsion, integration, validation, and alternative launch technology.

Seeker Technology Projects

A UV seeker has been developed as a breadboard, utilizing the ultraviolet data collected from the Delta 180 and 181 experiments. A cooled optics seeker with pinhole focal plane arrays and submillimeter feature size is being fabricated. An SWIR, non-gimbaled, arrayed seeker and cooled non-sapphire window is being fabricated to give an eightyfold increase in signal collection over the current endoatmospheric interceptor design. Gallium arsenide substrate millimeter-wave amplifiers for active radar seekers are now producing 1 watt per element. An MWIR, 128 x 128 element, focal plane array in HgCdTe and with on-plane digital compensation is now functioning.

Avionics Technology Projects

Advanced autopilots, using VHSIC and z-plane technologies, are under development and will reduce the size by a factor of 40 and increase their throughput by a factor of 4. Parallel processing and radiation-hardened designs have been engineered and foundries selected for their manufacture. A fully configured 1750A standard chip set has been integrated into wafer-scale electronics and is capable of supporting the SBI boost and PBV intercept mission.

IMU Technology Projects

Stellar navigation units are being designed and will be fabricated. The resonant fiber optic gyro and silicon accelerometers are being integrated into an advanced navigation unit which will measure 80 centimeters on a side for the GBI and 3 centimeters on a side for the SBI. A fully functioning interferometer fiber optic gyro (IFOG) is being integrated into LEAP.

Divert Control

Platelet technology and ClF_5 propellants are being combined to develop a higher performance engine for divert control. A low-weight, high thrust-to-weight ratio jet interaction unit is being built. One millisecond response time divert valves and hover capability have been demonstrated.

Rocket Axial Propulsion Technology Projects

Tremendous progress in axial propulsion for the SBI has made on-orbit weight reductions by a factor of four a reality while also increasing range. Low-cost first and second stage components for GBI are now being integrated. A fast-burn first stage and controlled burn second stage are being designed using high-pressure motors and gel propellants for application to HEDI.

Integration Technology Projects

Focal plane arrays (128 x 128), readout units, and dewars have been integrated into miniaturized, advanced interceptor seekers. Solid and liquid miniaturized divert and attitude control valves and motors have been built and are undergoing mission duty cycling prior to integration into the LEAP. A lightweight (400 gram) IFOG has been included in the projectiles.

Validation Technology Projects

A four-color, high-resolution scene projector is being procured, along with a high band-pass flight table and an environmental control chamber for the KHIL national interceptor test bed. The first operational capability of the KHIT and KHIL facilities has been demonstrated.

Alternative Launch Technology Projects

Accomplishments in the HVG area include large-scale gun firings at multimegajoule levels, rapid-fire gun development and test, a dramatic increase in shots fired per barrel, increased gun efficiencies, completion of advanced material studies and initiation of experiments, testing of advanced opening switches at the mega-ampere level, completion of the world's largest pulse power battery power supply to test large-bore rapid fire guns, completion of a 5-megajoule capacitor power supply, initiation of a 60-megajoule electrothermal gun system, and demonstration of more than 75 shots on a single set of bore materials. Accomplishments in other DOD programs include 9-megajoule firings of single-shot lab guns, increased understanding of gun scalability, and initiation of research in other electromagnetic launchers. During FY 1988, $13 million was spent on the Thunderbolt SUVAC II electromagnetic launcher, a test bed with the capability of firing a large projectile at a very high velocity.

6.3.4 Future Plans

Seeker development will support the near-term interceptor designs and continue work on promising alternatives to accomplish discrimination and CSO targeting. Among these will be a fast frame capability linked with cooled optics (mirrors, baffles) and z-plane (parallel) processing packaging. This will provide significant increases in acquisition range and signal processing rates. Handover requirements from external sensors will be reduced and the probability of kill will be increased.

Avionics work will continue to focus on autonomous navigation, fire-and-forget interceptors, and, for the space-based segments, lock-on-launch capabilities. Efforts will be continued to reduce the size and weight of the avionics/IMUs by incorporating micro-optic integrated gyros (MIGs) and tunable quartz gyros. These weight savings will be realized while increasing critical parameters by 100.

Divert control efforts will strive toward higher specific impulse propellants, like CIF_5 and hot solids, with increases of specific impulse by 50 percent and weight savings of 25 percent. These technologies will make deploying an SDS affordable. The first national beryllium test facility is now operational, and axial and divert motor characterization testing will proceed at an accelerated pace to support near-term SBI development.

Component technologies in propellants, casings, nozzles, and thrust vector controllers have matured sufficiently to allow the high burn rate HEDI propulsion technology validation booster and the low life-cycle cost GBI booster to be fabricated and begin ground testing.

Interceptor components required for fire control applications can now be integrated into experiments for laser radar trackers as described in the Firepond scenario (Section 6.1.4). More advanced navigation, seekers, and data processing will be modeled for incorporation into fire control experiments.

The communication technology effort will focus on communications components and their integration into concepts that are survivable and that can operate through severe jamming environments. Reducing the weight and size of this equipment will require more research advances.

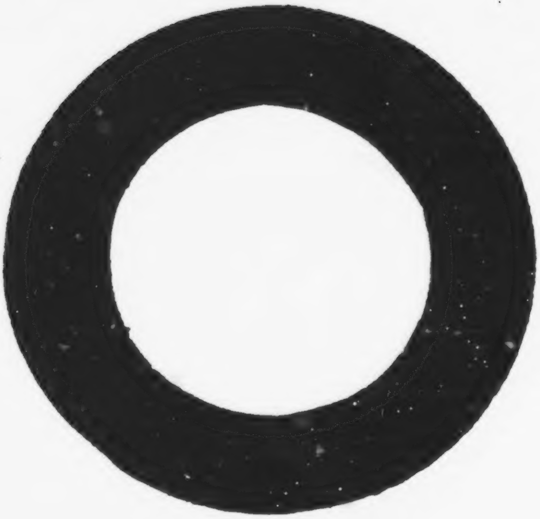
The integration programs will complete and deliver fully qualified ground test projectiles (GTPs). Studies are already under way to define those technologies and successfully integrate them into next-generation miniature projectiles.

The validation facilities (KDEC, KHIT, and KHIL) will continue to improve their technology testing capability. The KDEC facility will provide hardware validated interceptor simulations running on desktop parallel processors in real time within 3 years. The KHIT facility will upgrade to laser trackers for hover testing position accuracy. The KHIL facility will improve by adding multicolor scene projection capability and a high-frequency motion table. Efforts will be made to archive all testing lessons that have been learned to support those program offices designing future interceptors.

As components and integrated subsystems achieve validated maturity, responsibility for their development will be transferred to interceptor project offices for inclusion in their evolving designs. Seed programs in the technology base, like bionic eye seekers and artificial intelligence avionics, will greatly enhance preplanned product improvements or provide alternatives (e.g., dual mode seekers and stellar navigation), for more capable interceptors.

Section 6.4

Directed Energy Technologies



6.4 Directed Energy Technologies

Section 5.6 described the directed energy concepts being pursued for follow-on architectures. Those advanced concepts and the technology development activities that will make them proven alternatives for growth of the SDS are described in this section.

The DEW technology program discussed below brings together directed energy research efforts addressing four basic concepts (GBL, SBL, NPB, NDEW). Acquisition, tracking, point and fire control efforts support all four of these concepts and are discussed following the basic concept subsections. In addition, there is a continuing effort in concept formulation that supports all DEW concepts. This ongoing effort is designed to identify the technological content of the weapons system, to guide technology development, and to provide conceptual designs for evaluation in potential SDS architectures.

The SDI research program is focused primarily on non-nuclear technologies. However, it is critical to explore the feasibility of nuclear-driven directed energy concepts to understand the potential impact of any such systems that the Soviet Union might develop, as well as to determine the feasibility of these concepts for future SDI options. The Soviet Union has been conducting research in NDEWs for the past several years and some of its research predates our own. Because of this, an important aspect of our NDEW research is to understand the extent to which such weapons, if used by the Soviets, could counter U.S. retaliatory forces and destroy space-based elements of U.S. surveillance systems and a future U.S. strategic defense system.

6.4.1 Free Electron Laser/Ground-Based Laser

This section describes the technology goals of the FEL and GBL and discusses the project's accomplishments and future plans.

Technology Goals

The key goals pursued by the GBL project can be grouped into five areas (three are concept specific technical areas, another area is shared with other DEW concepts, and another is a functional integration area):

- Device scaling. The program should progress from the initial output power needed for proof of principle to the continuous power levels needed for initial deployment.
- Propagation and beam control. An adaptive optics system must be perfected to correct distortion of the laser beam caused by uneven heating of the atmosphere, atmospheric turbulence, and other phenomena.
- Space optics and beam control. The development and producibility of precision large optics and figure control in a dynamic environment, including wavefront sensing, is also required.

- Acquisition, tracking, and pointing (ATP). As with other DEW system concepts, the GBL must be able to acquire and track an uncooperative target and precisely point the weapon beam. The GBL must also be capable of establishing and maintaining the alignment between the ground station and the relay and mission mirrors and then demonstrating that a lethal laser beam can be transmitted through a distributed beam control system.
- High power integration. All of the above elements, including the device, the propagation and beam control systems, the optics, and the ATP must all be combined in one coherent entity. The first embodiment of this fully integrated system is the major GBL demonstration called the Ground-Based Free Electron Laser Technology Integration Experiment (GBFEL TIE).

Project Description

The ground-based FEL project is an intensive laboratory and field research project that will demonstrate the GBL technology needed to enter FSD. During FY 1988, approximately $12.6 million was spent to construct the supporting laboratory complex. The project is focused on five major objectives. First, the project will show that FELs can be built, integrated, and operated at multimegawatt power levels. Second, the project will demonstrate that a very high-power laser beam can be steered through a beam director, acquire and track a space target board, and deposit its energy on that space target. Third, the program will show that distortions on the laser beam caused by uneven heating of the atmosphere, atmospheric turbulence, and other phenomena can be compensated for and corrected on the ground using an adaptive optics subsystem. Fourth, it will demonstrate the systems integration and operation of a FEL, a beam control subsystem, and an atmospheric compensation subsystem. Fifth, the program will demonstrate the feasibility of a space-based relay mirror integrated with ground elements to validate the GBL concept for strategic defense.

To meet these objectives, the ground-based FEL project is focused on three major areas of parallel research. The first is the GBFEL TIE. This experiment addresses the ground segment components of lasers, beam control, adaptive optics, and facilities necessary to conduct a GBL proof-of-principle systems experiment at the White Sands Missile Range (WSMR), New Mexico.

The GBFEL TIE will resolve the most important issues of laser power generation and control, systems scaling, atmospheric compensation and beam propagation, and systems integration during the Dem/Val phase of GBL systems development. Following a successful experiment in the mid 1990s, this ground segment technology will provide the basis for FSD.

The second major activity of the GBL project is concerned with the space segments of the system. Here, relay and mission mirror spacecraft will be designed and subscale hardware fabricated during the Dem/Val phase. Once the GBL concept has been validated, a full-scale spacecraft will be designed and fabricated.

The third major focus of the GBL project deals with risk reduction and supporting technology. Issues of producibility, manufacturability, and quality assurance will be addressed. Of particular importance are the issues of nonlinear and cooled optics, large optical components fabrication, and coatings applications which are pursued in coordinated efforts with optics development in the chemical laser area. Because many of the ground and space segments of the GBL require high-quality optics, it is imperative that this area of technical research proceed in parallel with fundamental equipment research. The goal is to complete these efforts in time to support the Milestone II decision.

The questions of atmospheric propagation, thermal blooming, turbulence correction, and stimulated Raman scattering require supplemental computer modeling, laboratory research, and field experiments to ensure that the predictions for the larger-scale WSMR experiments will be successful. A horizontal path field experiment is currently planned to produce thermal blooming and to test the capabilities of adaptive optics to compensate under realistic thermal blooming conditions. Understanding the interaction of high-power laser energy with the atmosphere is also vital to the success of the GBL program. Therefore, several supporting national laboratory and university research projects have been established as risk-reduction efforts. The Low-Powered Atmospheric Compensation Experiments (LACE) will correlate laboratory results on low-power atmospheric compensation.

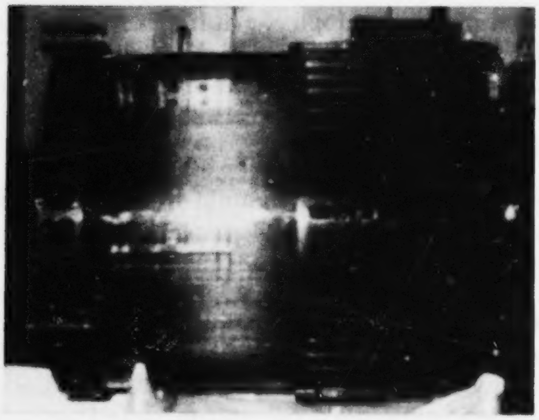
The other part of the FEL technology area deals with the development of a space-based FEL that will be able to address the strategic defense mission of the boost-phase intercept of ICBMs and SLBMs. It is designed to explore the technologies necessary to allow the operation of a short-wavelength, high efficiency FEL in a space environment. Initial studies have shown that a space-based FEL could perform at the same level as the space-based chemical laser with significantly less weight on orbit. In addition to the reduced weight, it would also provide an alternate technology path to the high-brightness requirements of the long-term mission. To effectively accomplish this goal at the lowest cost, the NPB and ground-based FEL programs are being used to complement this effort. Specifically, the NPB program will address the issues of operating an accelerator in space, while the physics of laser operation will be addressed by the ground-based FEL program. The space-based FEL will concentrate on those technologies necessary to bridge the gap between the other two programs.

The approach to providing growth in performance for the GBL system minimizes the change required to achieve increasing levels of performance. This approach allows the supporting technology base to concentrate on scaling the device to very high power levels, improving the efficiency and cost, and proving the feasibility for larger ground stations to support the higher power loadings.

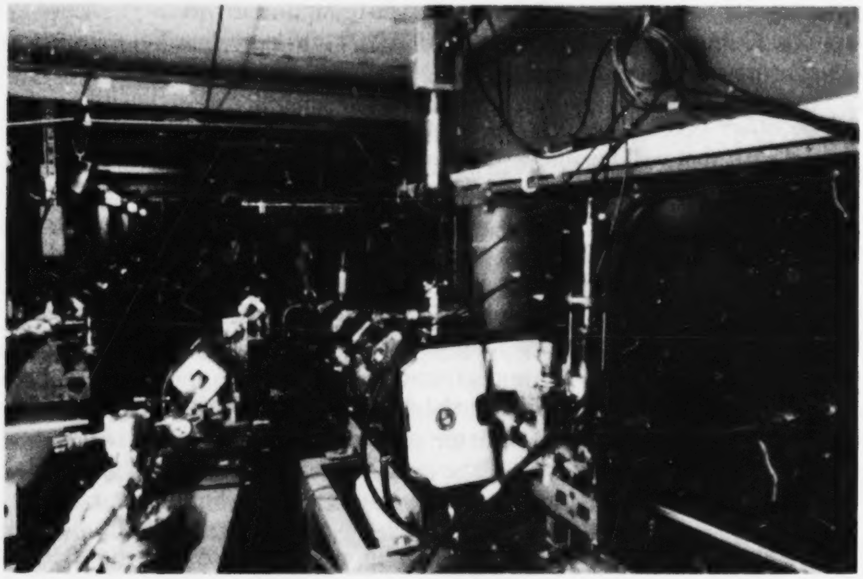
Accomplishments

Figure 6.4-1 shows examples of progress in GBL technology by identifying current hardware development with the functions required of such a weapon system.

Figure 6.4-1
GBL Technology Progress



The 80 cm telescope (left) is a major ATP experiment under way in the Starlab project. The GBFEL technology integrated experiment (below) will show that lethal laser energy can be efficiently transmitted through the atmosphere.



FEL technology has experienced rapid gains in the last several years. The induction linear accelerator (linac) version uses a high-current electron beam in a series of short pulses at moderate repetition rates. Because of the high-current electron beam, this type of FEL is an efficient amplifier.

In experiments at Lawrence Livermore National Laboratory (LLNL), the induction linac FEL has been demonstrated to operate with high efficiency at long wavelengths. Experiments with a 4-megaelectron-volt beam and tapered wiggler produced peak powers greater than 1-gigawatt at a 9-millimeter wavelength. Current experiments with the 50-megaelectron-volt Advanced Test Accelerator (ATA) and 25-meter-long wiggler have already demonstrated amplification at the 10.6-micron carbon dioxide laser wavelength. Amplification of the light from the master oscillator has shown agreement with theory.

High-brightness electron beams have been produced using thermionic dispenser cathodes. The brightness levels have increased several orders of magnitude since the first experiments on the experimental test accelerator. Current brightness levels are already adequate for the 1-micron wavelength goal of this program. Furthermore, these high levels have been achieved at high repetition rates using magnetic switching technology. A technique of guiding the electron beam through the accelerator, resulting in extremely small transverse motion, has been developed.

The second type of FEL candidate uses a radio frequency (RF) linac to produce a lower peak power beam in a series of short, high-repetition rate micropulses. The beam is accelerated directly by RF fields applied to a series of hollow cavities. This type of device, with its lower peak current, has been developed mainly as an oscillator, but amplifier configurations have also been designed.

RF linac devices have lased at extremely short wavelengths, demonstrated high efficiency, and served as test beds for the development of new, very high-brightness injectors. These injectors use a series of short visible laser pulses to eject electrons from the cathode by photoemission, resulting in high peak currents with high brightness. Grazing incidence optics have been developed and tested for ring resonators for radio-frequency FELs. In experiments at Los Alamos National Laboratory (LANL), parabolically shaped optical surfaces have expanded the optical beam and reduced the power loading on optical surfaces by a factor of about 50.

Experiments using low-power laser beams have demonstrated the ability to compensate for distortions in the atmosphere caused by turbulence. Using adaptive optics ("rubber mirrors"), a blue laser beam was propagated to aircraft, rockets, and the Space Shuttle. .Corner cube reflectors were used to obtain a return beam which provided a reference signal of wavefront distortion. Using adaptive optics to predistort the outgoing wavefront, the brightness of the outgoing beam at instrumented target rockets up to 600 kilometers away was improved by a factor of more than 1,000, as compared to an uncompensated beam.

High-energy laser propagation theory predicts thermal blooming and the possibility of producing uncorrectable optical distortions. Experimentation under idealized laboratory conditions at Lincoln Laboratory have induced thermal blooming but demonstrated that adaptive optics can compensate under these idealized conditions.

Substantial progress has been made in developing both adaptive optical elements and other optics for GBLs. A 2,000-channel, uncooled deformable mirror and wavefront sensor have been completed and are being tested. Two liquid-cooled deformable mirrors with 241 actuators are ready for polishing and coating. These components will be used in experiments for the GBFEL TIE. Three different approaches to aperture sharing elements are being investigated for application to the

GBFEL TIE, and subscale samples are being prepared for testing. The facility to evaluate coating damage has been used to evaluate many materials, including beryllium. A 2-meter coating capability has been established and demonstrated at a magnetron spattering facility with ± 1 percent coating thickness uniformity achieved on 2-meter optics.

Theory predicts that intensities greater than 1-megawatt per square centimeter may cause GBLs to lose intensity in passing through the atmosphere due to stimulated Raman scattering from atmospheric nitrogen. Laboratory experiments at Lincoln Laboratory have suggested that the effects of Raman scattering can be mitigated by broadening the frequency spectrum of the outgoing laser beam.

Future Plans

The following plans are keyed to an integrated GBL schedule. In FY 1989, the GBL project will select between the induction and RF FELs and award a contract to build a medium-power laser at White Sands Missile Range. Facilities construction of the common buildings will continue and final design for the technical facilities will be completed. Long-lead time procurement for key optics will be initiated.

Basic physics problems will continue to be resolved and the technology integrated into the GBL program. Laboratory tests should resolve the remaining basic physics problems and allow progression to subscale tests. Subscale tests should resolve any remaining propagation and scaling issues and allow fabrication of hardware for systems integration and testing. Relay mirror experiments, if successful, will validate the system concepts and enable full-scale testing to begin. Relay and mission mirror tests will serve to complete concept demonstration and validation and will run concurrently with full systems tests. Detailed design and acquisition for lasers and the Beam Control System (BCS) experiment will support a ground-based laser integrated test.

In the area of space segment technology, current program plans call for smaller initial mirrors in the space segments for test and, potentially, initial deployment. These smaller platforms will provide boost-layer destruction and midcourse discrimination capability against current threat systems in a shorter development time, and provide a lower cost program. As the full-scale space components are deployed, these platforms will become sensor platforms to augment the already deployed systems.

The GBL project has joined with other space research efforts within the SDI to verify needed ATP/FC capabilities. Future ATP experiments, such as the Relay Mirror Experiment (RME), Starlab and Zenith Star, will provide essential design information necessary for the GBL full- and subscale satellites to reach their launch schedules with the ATP data needed and without duplicating other already funded and scheduled research.

6.4.2 Chemical Laser/Space-Based Laser

This section describes the technology goals for the chemical and space-based lasers and the projects' accomplishments and future plans.

Technology Goals

The critical technical issues for the SBL element can be grouped into the following five areas:

- Laser device. The program should progress from the present capability of the chemical laser ground test facilities to the ability to generate near diffraction limited high power in a space compatible configuration.
- Beam control. The system must provide a means of sampling the outgoing wavefront and analyzing it with a wavefront sensor to provide corrections to the deformable mirrors which control the wavefront. The system must also provide the capability to retarget rapidly while maintaining excellent beam quality.
- Optics. The capability to produce large adaptive primary mirrors must be developed.
- ATP. As with other DEW system concepts, the SBL must have the capability to acquire, track, and point in space.
- High-power integration. All of the above elements, including the laser device, beam control mechanisms, optics, and ATP, must come together to demonstrate a low loss system capability at high megawatt power levels.

Project Description

The primary effort in the area of the laser device involves demonstrating the feasibility and scalability of the hydrogen fluoride (HF) chemical laser and associated optics. The Alpha laser will provide these demonstrations.

Beam control efforts include wavefront control activities investigating beam sensing, beam control, and rapid retargeting concepts. These concepts are being investigated for high-power infrared and ultraviolet/visible beams from single and multiple aperture systems. Various advanced concepts, such as nonlinear optics, wide field-of-view telescopes, and phased array technology are being developed and tested.

Wavefront control activities also include the Large Optics Demonstration Experiment (LODE) program. LODE addresses the generic technical issues associated with the ability to sense and control the high-energy laser wavefront in a dynamic environment. The LODE program consists of two elements: (1) a laboratory model experiment with a segmented primary mirror, and (2) beam control technology experiments. The latter will demonstrate single aperture beam control technology which is scalable to very high-brightness laser performance levels. During FY 1988 approximately $3.2 million was spent on the high-energy laser systems test facility (HELSTF) upgrade, WSMR, New Mexico, to provide a technical activity support area.

Optics efforts support both device and beam control efforts. They seek to develop and evaluate high-performance materials, structures, and high reflectance coatings for primary mirrors and advanced resonators required for very high-brightness, space- and ground-based laser systems. This includes a fabrication technology for manufacturing large, segmented mirrors, development and testing of high-power IR and short-wavelength mirror coatings, and development of advanced cooling concepts for mirrors under very high radiation loads. Development of transmissive elements and unique components for beam control applications is part of this effort.

Design and development efforts in the Large Advanced Mirror Program (LAMP) are also included in the optics area. LAMP, a large, lightweight, segmented space mirror, consists of face sheets, fine figure actuators, reaction structures, segment actuators, base plates, and the sensors and electronics necessary for active mirror surface control. Active control is used to maintain the mirror shape in the face of thermally induced distortions.

Should the threat evolve to the point where still more capable weapons are required, the individual modules would be aggregated into higher brightness configurations. There are several approaches to doing this, such as coherent coupling of individual modules and apertures using a master oscillator/power amplifier approach and conventional array phasing, or coherent coupling of individual device modules through a single very large aperture using nonlinear optics to couple the devices. Longer-term candidate technologies for very high-brightness, space-based laser systems include shorter-wavelength chemical lasers and the RF FEL.

The last major effort is the Zenith Star program. Zenith Star includes the integration of the Alpha laser, LAMP mirror, LODE beam control, and acquisition, tracking and pointing technologies for a series of high-power ground and space tests. The Zenith Star space experiments complete much of the Dem/Val phase for the space-based chemical laser. Zenith Star plans include the following:

- High-power experiments in which the Alpha laser beam irradiates cooperative and augmented objects including thrusting solid-fueled and liquid-fueled rocket test devices, instrumented target boards, and midcourse objects.
- Low-power experiments to investigate and collect data on active tracking and precision pointing against unaugmented rocket test devices, plume phenomena in both active and passive tracking modes, large beam expander repointing, and space and earth background.

A key feature of the Zenith Star effort are the future ground tests which will demonstrate successful integration of beam generator, beam control, and the large telescope.

Possible cost growth of the Zenith Star program was identified by Congress as an item of special interest. Zenith Star cost is being controlled across a broad front ranging from contract negotiations to the scheduling of long-lead item procurement. The negotiated cost for Phase IIIA, Design and Verification, is based on independent cost estimates and detailed evaluation of the labor hours. The next line of defense is tailored earned value reporting accompanied by independent cost review and monthly management reviews. The contract has been structured to motivate the contractors to control short- and long-term costs. The incentive fee for prime and sub contractors is structured to reward underruns and to escalate penalties for overruns including no fee for excessive overruns. The performance fee, besides going to the prime contract, is directly channeled to both employees and subcontractors. In anticipation of possible technical problems, the experiment technical objectives are being prioritized and the marginal cost for each objective is being identified. If overruns do occur due to technical problems, SDIO is prepared to adjust experiment objectives to avoid cost growth due to funding profile changes. Long-lead item procurement is being monitored so that the schedules can be adjusted for short-term problems. SDIO is instituting cost containment procedures in all controllable areas.

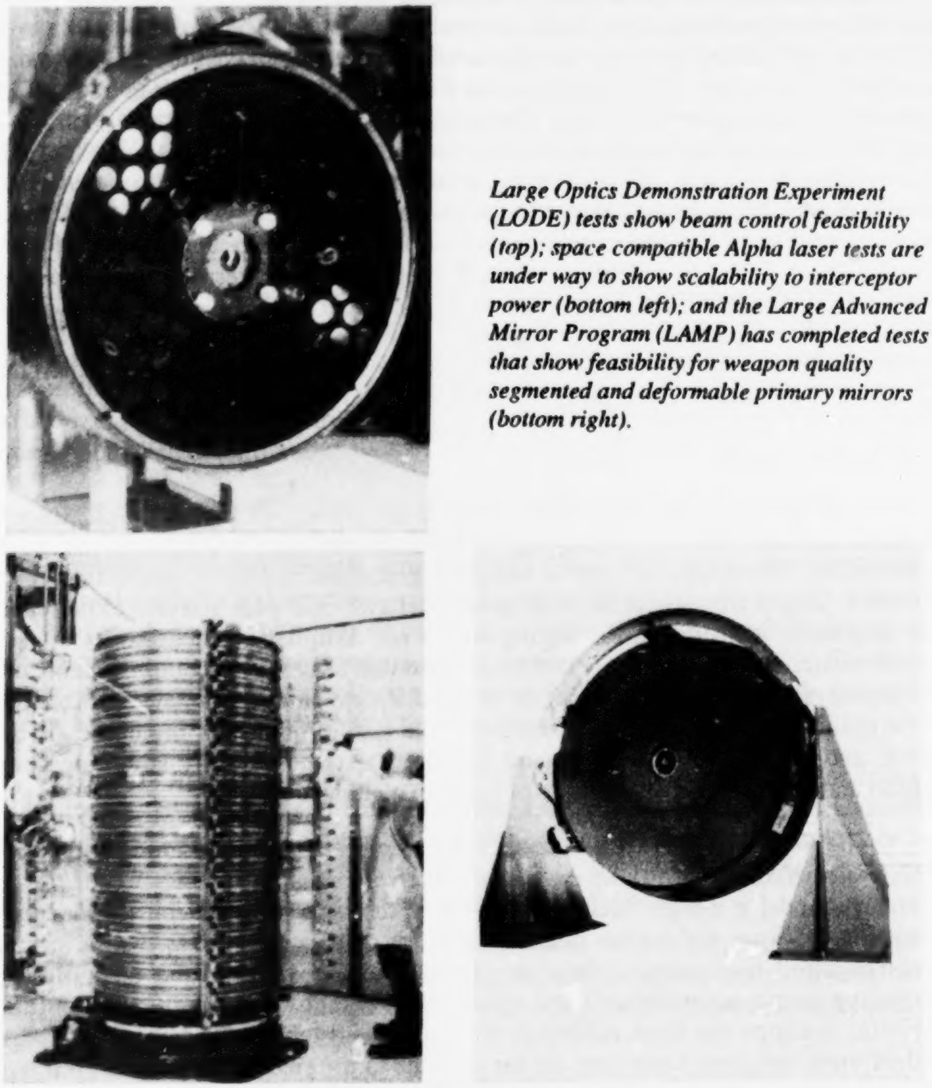
Accomplishments

Examples of SBL technology progress are shown in Figure 6.4-2. Excellent progress has been made in developing the laser technologies required for the modular battle station. The Alpha HF laser is being integrated and tested. Alpha technology and hardware designs are compatible with space operation and were selected to be scalable. The diagnostic instruments for testing Alpha are designed to measure its operating characteristics in a manner sufficient to confirm that scaling. Accomplishments of the Alpha program include the completion of the diamond-turned annular resonator optics of the cylindrical gain generator assembly; the facility in which the device is being tested; and a series of cold-flow and hot-flow tests confirming stable combustor ignition and the thermal performance of the gain generator assembly.

The initial series of LODE laboratory model tests was successfully completed in 1987, confirming the utility of outgoing wavefront sensing for beam control. This laboratory model is a high-fidelity emulation of the hardware and controls needed for correcting the jitter and higher order aberrations of a laser beam to the performance levels required for strategic defense. In addition, scaling of the technology for fabricating single-color holographic optical elements in highly reflective multilayer dielectric coatings has been achieved, and successful laboratory testing of a narrow field-of-view outgoing wavefront sensor scalable to the size and performance required for a first generation weapon deployment is complete. Work on multicolor holographic grating elements and wide field-of-view outgoing wavefront sensor laboratory experiments also began in FY 1988.

Fabrication of a large, lightweight, segmented adaptive mirror (LAMP) has been completed. Acceptance tests were also completed in late 1988. The mirror design and fabrication techniques were selected with scaling as a primary goal. The mirror segments were produced with a largely automated polishing procedure specifically

Figure 6.4-2
SBL Technology Progress



Large Optics Demonstration Experiment (LODE) tests show beam control feasibility (top); space compatible Alpha laser tests are under way to show scalability to interceptor power (bottom left); and the Large Advanced Mirror Program (LAMP) has completed tests that show feasibility for weapon quality segmented and deformable primary mirrors (bottom right).

developed for this purpose. This greatly relieves concerns for producing large quantities of precision optics. A process to spin cast large glass mirrors has been developed and tested.

Experiments designed to confirm growth potential to very high-brightness concepts have been completed. They prove that beams from combustion-driven, HF chemical lasers can be coherently combined either by coupling the resonators themselves or by employing master oscillator-power amplifier configurations. On-axis phasing of multiple apertures at low power has been demonstrated in several laboratories. The critical issues of off-axis steering and control are being resolved by SBL technology base activities.

During the past several years, considerable progress has been achieved in two technologies that may considerably enhance the performance, affordability, and producibility of both initial and advanced SBL platforms.

Future Plans

The chemical laser technology effort will continue with the development of chemical lasers and related component-level technologies and then concentrate on integration at the system level. The final testing of the Alpha laser device will essentially complete the Alpha project. Successful completion of this project will demonstrate the technical feasibility of the HF laser device and validate the computational methods for confident scaling of the single-module devices to higher powers. Technical knowledge from the Alpha project will be applied as subscale testing progresses and system integration/testing begins.

Beam control efforts required for the FSD prototype include activities to develop and demonstrate control technologies for rapid retargeting of high-energy lasers. This advanced beam control system will provide smooth, reactionless scanning of a group of targets. The requirement is to develop a capability to retarget rapidly while maintaining high beam quality. Laboratory experiments will verify key subsystem concepts.

A high-quality optical segment of a large lightweight mirror will be fabricated and tested. The Starlab experiment will help resolve ATP/FC issues. Information from these programs and experiments will then be applied to the Zenith Star ground tests.

Zenith Star ground and space experiments will complete the data base for a decision on developing the space-based chemical laser for strategic defense. The ground experiments will integrate and functionally test the two principal segments of the Zenith Star research spacecraft: the forebody, consisting of a large beam expander incorporating the LAMP mirror and sensors for ATP/FC, and the aftbody, consisting of the Alpha laser and high-power beam control system. Subsequent to ground testing, these two segments will be integrated for a series of high- and low-power space tests to demonstrate technology achievement needed for the initial deployment of SBL modules. These tests will also provide key experiments that verify the ATP/FC and space beam control approaches for GBL concepts. Successful completion of Zenith Star will essentially serve as concept demonstration and validation and enable the start of element development.

The critical experiments for the SBL element revolve around the high-energy laser device, high-power beam control and optics, ATP/FC, and platform integration. Most of the verifications of the high-energy laser device will be resolved during ground testing, but laser exhaust management approaches can only be resolved by space tests.

HF and other gases are ejected radially outward during HF chemical laser operation. To avoid the possibility of degrading optics or other components, immediate and longer term distributions of gases about the spacecraft must be well known.

Space tests with a high-power beam are also required to verify the principal high-power beam control and optics performance. Excellent beam quality and line-of-sight stability on accelerating targets must be maintained. These requirements are so stressing that very long, optically quiet paths are required to obtain sufficiently accurate measurements. A very large, lightweight beam expander/pointer is required. Both spacecraft segments contain many load paths and disturbance sources, including coolant flowing at tens of gallons per minute, and reactants, propellants, and exhaust flowing at tens of pounds per second. This extremely complex spacecraft cannot be modeled with the accuracy required to confidently predict the efficacy of the high-power beam control system. Because the high-power device and beam control components are closely coupled through the space-based laser platform and very high performance levels are required, only a high-power space test can provide the confidence needed for a development decision.

ATP/FC functions that must be demonstrated include detection of the plume, acquisition and fine track of the missile body, and aimpoint selection and maintenance during high-power irradiation. Zenith Star space experiments contribute to verification of these functions with a series of low-power experiments using thrusting, unaugmented and uncooperative targets against realistic backgrounds, and high-power tests using critically augmented, cooperative targets. The high-power tests will confirm that low-power results are not compromised by effects such as flow-induced disturbances, thermal loading of the high-power beam on the optics, and scattered high-power radiation.

6.4.3 Neutral Particle Beam Technology

This section describes NPB technology goals and projects and discusses NPB accomplishments and future plans.

Technology Goals

As the NPB system concept evolves and the research, development, and acquisition process proceeds, the following key technology goals are being addressed:

- The development of a high-brightness, continuous-wave (CW), automated-ion source. CW operation is desired for fast retargeting during target discrimination.
- Maturation of low-energy and high-energy accelerator technologies based on progress made in ramped gradient drift tube linac (DTL), radio frequency quadripole (RFQ), and cryogenic DTL component development.
- Perfection of magnetic optics components for beam funneling and expansion with low induced emittance growth.

- Scaling of techniques for a factor of two increase in size of foil neutralization technology and development of advanced photoneutralization techniques for advanced systems.
- Optimization of techniques for sensing beam direction and for precise beam pointing.
- Development of a system acquisition, tracking, pointing, and fire control subsystem.

Project Description

The NPB project has a technology development segment, a ground-based technology integration segment, and a space experiments segment. Together, these segments address the key technical and system issues associated with the feasibility of deploying an NPB system capable of boost and post-boost intercept as well as midcourse discrimination. The ground-based segment experiments are (1) the Accelerator Test Stand (ATS), which is used as a low-energy technology test bed; (2) the Ground Test Accelerator (GTA), which will demonstrate the operation of an integrated NPB system with mission-capable performance parameters; and (3) the Continuous Wave Deuterium Demonstrator (CWDD) which examines high duty factor and deuterium operation at low energies. Allocating issue resolution between GTA and CWDD instead of building one large machine resulted in significant cost savings. The space experiments are the Beam Experiments Aboard Rocket (BEAR), which addresses the basic space operability issues, and Pegasus, an orbital experiment which will address additional NPB issues that cannot be tested on the ground.

The technology development segment concentrates on developing the enabling technologies for the ground and space experiments and initial deployable NPB systems. Work in the enabling technologies covers development of ion sources, RFQs, cryogenic and ramped gradient DTLs, magnetic optics, foil neutralizers, and beam sensing. Additionally, there are joint projects with other SDIO directorates to address power and materials issues.

In the ground-based integration experiments, the ATS is used to integrate and test low-energy components, many of which will be part of the GTA. The GTA is the primary test bed for the initial NPB system development. It is designed to demonstrate scalability and differs from entry level weapon parameters in energy and duty factor only, which will have no impact on the feasibility decisions. Also, GTA will be used as a test bed for advanced NPB technologies such as high-brightness ion sources, advanced neutralizer development, and ATP/FC. The design philosophy for GTA is to incorporate space-traceable technologies where appropriate. The space-related technologies that will be incorporated into the GTA include a 180-degree bend for compactness, lightweight efficient RF power modules, cryogenic operation for higher electrical efficiency/lower platform weight, and automation for rapid start-up and operation.

CWDD addresses the technical issues associated with CW operation, which are (1) generation of a CW ion beam with the requisite quality, current and particle type;

(2) stable operation of such a beam for expected operational requirements; and (3) management of the waste heat. The requirement for CW operation was identified by the concept definition studies in order to meet expected target handling rates for the various missions. The CWDD will consist of an ion source/injector, an RFQ, and one or more DTLs. This configuration allows pertinent issues to be addressed while minimizing radiation hazards and the cost of RF power.

The NPB space experiments are designed to address specific issues requiring resolution in the space environment. The BEAR flight is a non-orbital rocket flight that will provide preliminary data to the Pegasus design and to the NPB space operation feasibility assessment. The Pegasus experiment will be an orbital flight designed with operating parameters required to address specific issues associated with operation in a zero-*g*, space plasma environment. Pegasus will use technology from the SDIO power, ATP, sensors, and materials and structures programs.

As the threat evolves, the growth paths of the particle beam concept include (1) the deployment of increasing numbers of weapon platforms and sensors in space which adds more weapons into the battle and reduces the average ranges of engagement, and (2) increasing the individual weapon platform performance. A primary option that is being maintained for increased performance is to use deuterium particles in lieu of hydrogen for the beam.

Enhanced NPB performance concepts to counter a robust Soviet response to initial SDS development require enhancing technologies such as photoneutralization and advanced beam sensing. High current beams for advanced NPBs require reductions in platform weight that are being addressed in materials research such as high-temperature superconductors.

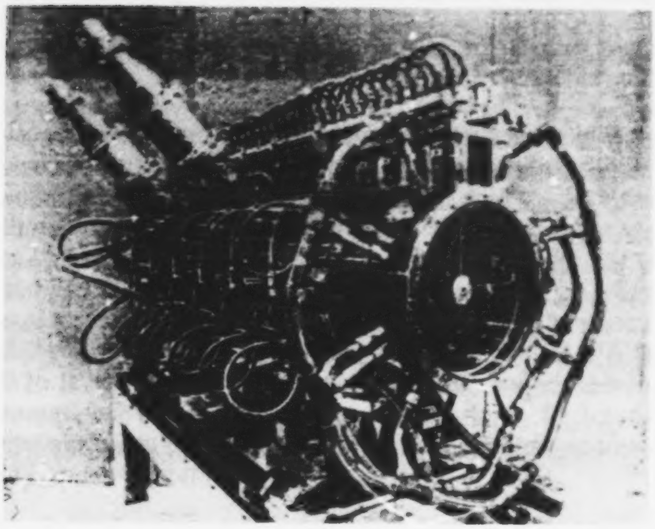
Accomplishments

The NPB technology development effort has made significant progress in all of the technologies associated with the initial NPB weapon/discrimination system. Examples of progress in particle beam technology are shown in Figure 6.4-3. Not only has hardware been built for every key element of the system, but significant and in some cases unexpected progress has been demonstrated toward achieving required operating parameters.

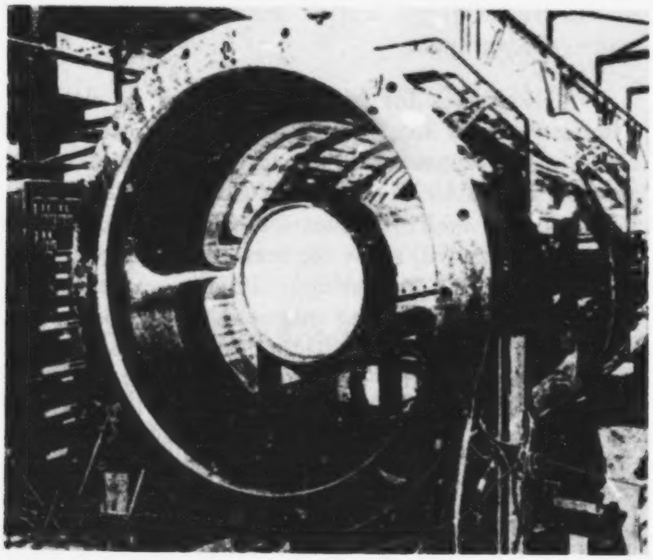
Two areas of recent NPB accomplishments with particular significance are the magnetic optics/telescope and the foil neutralizer. The one-meter magnetic optics was operated on the 50-megaelectron-volt (MeV) beamline at Argonne National Laboratory under automated control and obtained a beam divergence near weapon requirements. Large foil neutralizers have been manufactured. The success of these programs provides high confidence in the ability to build the required telescope and foil neutralizers.

The ground segments are proceeding; GTA has completed the preliminary design review (PDR) milestone and the GTA facility will be ready for occupancy in mid

Figure 6.4-3
Progress in Demonstrating NPB Technologies



The ramped gradient DTL (left) can be operated at 80 mA and 2.2–4.4 MeV/m.



A large-bore magnetic optics lens (right) has been fabricated and tested.

FY 1989. The CWDD development contract was awarded in FY 1988 and the PDR occurred in December 1988. A contract award is expected in mid-FY 1989 for the development of the NPB Power System Demonstrator (PSD) which addresses prime to RF power generation issues.

The BEAR effort completed the critical design review in FY 1988 and is scheduled for launch. The basic issues to be addressed by Pegasus were defined in FY 1988 and an integration meeting with the involved parties was held in the first quarter of FY 1989. A contract award for actual development is expected before the end of FY 1989.

Future Plans

The overall NPB project has based its development efforts on a comprehensive program planning process. This effort emphasized the identification and resolution of critical technical and systems issues, which resulted in a well structured and defined program. Work will continue in developing the enabling technologies and integrating them into GTA and CWDD. Ion source funneling experiments will be conducted as a risk reduction effort to ensure proper beam current and divergence. GTA-24 is a preliminary step in the GTA process and will allow resolution of many issues at lower energies. The results from BEAR, technology development, and GTA will be available in time to affect the Pegasus design process, thereby reducing risk. Several of the system issues will be addressed by other projects such as the Army Background Experiment (ABE) (neutron sensors) and Starlab (ATP/FC). The NPB project is being coordinated with these efforts.

Readiness for Milestone I or entry into Dem/Val will follow completion of major technology proof-of-principle accelerator experiments with the Accelerator Test Stand and demonstration of beam line characteristics on the GTA as well as completion of the BEAR flight test to demonstrate the feasibility of neutral particle beam propagation in space.

Readiness for Milestone II will be determined primarily by the ground demonstration of accelerator scaling, integration, and automation with the High-Energy GTA. CW operation with deuterium will be demonstrated with scalable parameters starting in FY 1992 on the CWDD. The flight experiment, presently known as Pegasus, will address issues that can only be resolved in space. A Power System Demonstration will show the feasibility of multimegawatt prime and RF power with space-compatible technology. Finally, a combination of ground experiments and demonstrations involving magnetic optics, beam sensing, and optical tracking and pointing culminating in flight tests such as Starlab and the Active Midcourse Experiment (ACME) will show feasibility of the rapid retargeting necessary for interactive discrimination.

The GTA, a key effort in supporting milestone decisions, will be operating in FY 1991. The GTA test series will address all but two of the technical issues (CW operation and deuterium particle) pertinent to the generation of a weapon/discriminator grade particle beam. While the accelerator will be constructed to be CW capable, it will be operated in the pulsed mode to reduce costs. The GTA is currently being constructed at LANL in a joint effort with a DOD contractor.

The CWDD will achieve an initial capability to support tests in FY 1992. It will then address the remaining two issues of beam generation not addressed by the

GTA. CWDD will be a low energy accelerator because the difficult issues concerning CW particle beam generation are resolvable at the low-energy end of the accelerator. It is more economical to address these issues using a separate accelerator. The CWDD will be built and tested by industry beginning in FY 1989.

NPB space experiments will build on and contribute to the ground-based experiments. The BEAR flight from WSMR will provide valuable data concerning space operability that will directly feed, in conjunction with the GTA experimental hardware, the design of the Pegasus experiment hardware. Experiments in other programs will also support NPB technology needs. Space Power Experiments Aboard Rockets (SPEAR), an Innovative Science and Technology project being developed in conjunction with the NPB program, will look at power conditioning components exposed to a space environment. ABE, which is piggybacked on the Laser Atmospheric Compensation Experiment (LACE)/Relay Mirror Experiment (RME) experiments in the ATP/FC project, will measure the atmosphere-reflected neutron background for target/decoy discrimination. The information gathered from SPEAR, ABE, the ATP/FC experiments, and the flight of Pegasus will fulfill the space experimental requirements for the NPB prior to Milestone II. Low-power GTA tests, followed by high-power GTA tests, will complete Dem/Val of the NPB, and will support an FSD NPB test in the late 1990s.

6.4.4 Nuclear Directed-Energy Weapon Technology

This section describes NDEW technology and accomplishments and future plans.

Project Description

The NDEW research path is based on a program of theoretical and computational development in concert with underground nuclear tests and related laboratory experiments. A DOD and DOE cooperative program is conducting mission analyses as well as exploring platform engineering concerns.

Accomplishments

Several dedicated underground tests have been conducted to support the NDEW technology program. Experiments and analysis also continued to support understanding of NDEW physics, with emphasis on diagnostics output characteristics, and weapon effects.

Future Plans

The Department of Energy will continue NDEW nuclear underground tests. Determination of overall weapon concept feasibility will continue to be studied by DOD.

6.4.5 Acquisition, Tracking, Pointing/Fire Control Program

This section describes the ATP/FC program technology goals and the program's accomplishments and future plans.

Technology Goals

Major issues for the ATP/FC project include demonstrating technology for the following:

- Initial acquisition of boost phase or midcourse targets against complex backgrounds which can include missile exhaust plumes, earth, atmospheric, and celestial radiance sources.
- Very rapid retargeting of the weapon beam in order to maximize multitarget engagement rates.
- Precise pointing of the weapon beam at high angular tracking rates and in the presence of disturbances and countermeasures.
- Autonomous control of multiple-target engagements.

Project Description

To effectively address such a broad scope of technologies within constrained funding, an investment strategy has been developed for the ATP/FC project which seeks to maximize early accomplishment in the most critical areas. Available hardware technology is exploited in early space experiments to gain confidence in operating in the space environment and in "scoring" of performance. Experiment objectives and hardware development are kept limited to emphasize control of cost and schedule. To the maximum extent possible, the ground technology base and laboratory experiments are directed toward developing those components needed for advanced performance levels. Supplementing space experiments to provide more complete technology issue coverage, and in some cases, reduced levels of experiment fidelity and functional integration are accepted in order to control costs. Both the early space experiments and the technology base provide the groundwork for future full fidelity space tests. The substantial degree of commonality of ATP subsystems among the DEW concepts allows the major issues to be addressed in an integrated program, augmented with limited concept-specific tasks.

Efforts in the ATP/FC project are in three related areas: (1) ATP/FC and GBL space relay experiments; (2) ATP/FC technology base development, including laboratory experiments and test beds; and (3) GBL space relay technology base. ATP/FC and GBL space experiments are under development to address both generic and concept-specific issues that can be adequately resolved only in space. These experiments include LACE and RME, both of which are to be launched on expendable boosters; Starlab, to be made ready for a Shuttle flight; and the ATP portion or Science Module of the Zenith Star experiment.

Efforts within the ATP/FC technology base address major tracking/pointing component performance issues, and the development of technologies for advanced concepts. These efforts include rapid retargeting of large, agile space structures; advanced tracking techniques for DEW targets at long-range, precision pointing controls; target engagement decisions (fire control algorithms); and end-to-end ATP/FC technology integration.

In the GBL space relay technology base, efforts are under way in coordination with GBL efforts to provide the requisite space relay technology. Space relay technology development efforts apply to relay mirrors which reflect the laser beam transmitted from the ground station and to mission mirrors which receive the relayed beam and focus it on the target. The two candidate concepts for the relay and fighting mirror spacecraft being pursued are (1) the flat, or nearly flat, monocle and afocal mirrors and (2) the bifocal mirrors with two coupled beam receiver and director telescopes.

Accomplishments

The Talon Gold ground experiment previously demonstrated the technology for high-precision integrated pointing and tracking. The technologies developed and validated include high-bandwidth beam stabilization, low-bandwidth target tracking, and vibration isolation using magnetic suspension. This experiment has contributed to resolution of key SBL issues including boresight accuracy and closed-loop pointing stabilization in the presence of mechanical and optical disturbances.

A spacecraft dynamics simulator for rapid retargeting and precision pointing was completed and became operational in FY 1987. This simulator is a hybrid, which includes both control software and hardware in real-time motion, and is truly a unique resource applicable to all DEW concepts. The simulator has demonstrated the feasibility of mechanical rapid retargeting using modal avoidance retargeting control algorithms.

Fire control decision algorithm and phenomenology modeling activities included collecting booster plume data in the IR, visible, and UV wavelengths using available sensors such as Probe and HICAMP, and observing both static firings and actual launches. These efforts have expanded the data base and are being used to upgrade current computer models of plume observables. There have also been laboratory demonstrations of real-time decision algorithms needed to locate the booster with respect to the plume image, using both computer-generated and actual plume and background scenes.

In pointing and control efforts, analytical predictions of mechanical disturbances on board SBLs, the space segment of the GBL, and NPBs were completed. The Space Active Vibration Isolation laboratory model demonstrated large-scale broadband vibration isolation in 1 degree of freedom for precision pointing structures. In the Passive and Active Control of Space Structures effort, critical structural damping was demonstrated on substructures similar to those which might be used on a DEW platform. State-of-the-art precision gyroscopes have been tested to determine their capability to meet DEW performance requirements for inertial measurements.

Concepts have been developed for both relay and fighting mirrors for the space segment of the GBL. Both planar afocal mirror (single mirror) and bifocal (two telescope) spacecraft concepts with rapid retargeting have been formulated. The fabrication of lightweight, half-scale afocal mirror segments has been completed, and an integrated ground experiment is under development. In the bifocal technology task, component fabrication has been completed and integration is in progress for a demonstration of a precision alignment reference transfer system (ARTS) between tracking and pointing telescopes.

Space experiment hardware and ground facilities are being completed for the LACE and RME projects. Starlab has completed all critical design review (CDR) milestones; experiment hardware is being fabricated and integrated into the Spacelab module. Risk-reduction laboratory tests have been conducted for key elements of the experiment.

During FY 1988, SDIO spent $1.8 million at Cape Canaveral and $8.0 million at Wake Island to construct and modify launch and data collection test support facilities. These upgrades were necessary to carry out research and tests associated with ATP technologies.

Future Plans

The current efforts in bifocal relay technology will be completed in FY 1989 with the testing of the ARTS and the outgoing wave sensor laboratory experiment. Planned efforts in monocle relay technology include an integrated control demonstration of the monocle mirror segment in FY 1989.

The Attack Management Test Bed will become operational in FY 1990–91. It will simulate the weapon functions of a DEW platform (configurable for different concepts) and is being designed to interoperate with the National Test Bed. The Attack Management Test Bed incorporates validated booster engagement, damage assessment, and multiple-target fire control algorithms. It will validate technology interfaces, test new ideas, and demonstrate the feasibility of autonomous execution of ATP/FC functions within ballistic missile defense timeline constraints.

Pointing and control demonstrations in FY 1990–92 will demonstrate the attenuation of severe mechanical disturbances in representative large, lightweight optical structures, and will include completion of an integrated structural control simulation model. Demonstration of optimal retargeting control strategies and an investigation of the utility of wide field-of-view optical designs will be accomplished on the rapid retargeting simulator in FY 1990.

Tracking and pointing experiments will be conducted by Starlab in a future mission of the NASA Spacelab. A major objective of this flight is to demonstrate, using active and passive sensor arrays, precision tracking of and precision pointing to boost-phase targets. This is done by performing handover of the booster hardbody location from coarse plume tracking to a fine-tracking sensor, actively tracking the booster hardbody, and pointing a controlled, low-power laser beam at a selected aimpoint on the booster. Starlab will demonstrate autonomous rapid retargeting and midcourse object deployment, tracking, and signature measurements. Advanced space qualified optical components will be tested, including ultra-lightweight mirrors, a five-degree of freedom secondary mirror, deformable mirror, wavefront sensor, and illuminator laser. A secondary experiment will test submarine laser communications. Starlab will also collect extensive phenomenology data on plumes, space targets, and backgrounds. High-resolution data will be obtained in UV, visible, and SWIR bands to verify and extend existing computer models.

The RME spacecraft is scheduled for launch on an expendable launch vehicle. The purpose of the RME experiment is to receive a laser beam generated on the ground and transmitted through the atmosphere and to precisely reflect the beam to a ground diagnostic target array. It will be a functional demonstration of GBL uplink pointing and relay mirror control technologies.

During the initial phase of the GBFEL TIE project, a lower-power laser beam will be directed toward a diagnostic satellite to validate atmospheric compensation technology. The LACE spacecraft will be launched on an expendable launch vehicle. LACE will carry as an additional payload a UV plume sensor to collect high-payoff data on rocket plumes and earth backgrounds in the near- and mid-UV spectral regions. LACE will also carry an experiment (ABE) to measure neutron background flux to support the NPB.

Finally, the most ambitious ATP/FC space experiment currently planned is included as the "science module" of the Zenith Star effort described within the SBL project. This space experiment will provide full performance sensor testing and validate control of a large space optical structure with submicroradian line-of-sight control. It will also provide vital data collection during the high-power tests.

Section 6.5

Other Key Technologies

6.5 Other Key Technologies

This section provides an overview of the supporting technology projects on two levels. One set of key technologies focuses on survivability, lethality, and countermeasures. They enhance functional survivability of potential strategic defense force elements in hostile environments and reduce uncertainties in the DOD's capability to predict vulnerability of enemy targets. Another set of technologies resolve SDI-unique problems in power and power conditioning, and materials and structures. Research in this area is critical to the development of a survivable and effective strategic defense system.

Combined, these technology projects provide a formidable source of technology development and assessments of technology requirements, tactics, and strategies; they ensure survivability of the SDS to mission completion in the face of determined defense suppression attacks. In addition, they provide essential data on weapon-target interaction (for kill) and probe-target interaction (for interactive discrimination) to assess SDI Program requirements. Equally important, they d[illegible]p lethality criteria that determine performance requirements for candidate weapon c[illegible]epts. Supporting technology projects also coordinate the development of power generation, conversion, and conditioning subsystems for SDI program elements and ensure that materials and structures needed for engineering development of a strategic defense system are available.

6.5.1 Survivability Project

This section discusses the technology goals, project descriptions, accomplishments and future plans of the survivability project.

Technology Goals

The primary focus of the survivability project for FY 1989–91 is SDS Phase I. This phase will employ current and near-term survivability technological capabilities in addressing a near-term threat. Follow-on phases will address far-term threats utilizing future technical achievements. Five key issues have been identified which, when implemented as part of an integrated project, will lead to overall SDS functional survivability. These key issues are described as follows:

- Phase I threat definition. Common, credible baseline and responsive threats will be coordinated between the intelligence and systems engineering communities and made available to element designers and technology developers.
- Survivability approaches. Combinations of survivability options will provide maximum survivability at minimum cost.
- Technology development. The required survivability technology will be developed and made available to system designers.

- Technology infusion. Technologies developed through the survivability office will be provided to the element designers.
- Test, evaluation, and validation. Survivability performance will be verified at component and subsystem levels to assure low risk and adequate system-level performance.

The SDS Phase I may be subject to Soviet attack at any time during its life, beginning with deployment. Such attacks may be covert or overt and may be made by a variety of defense suppression threats (DSTs).

The primary goal of the survivability project is to ensure an SDS functional effectiveness sufficient to meet or exceed JCS requirements against the ballistic missile threat—even in the face of a determined DST attack. To meet this goal, both active and passive survivability techniques selectively will be used and balanced to assure that system survivability is effective and insensitive to changes in growth of the DST.

Project Description

To control cost, enhance effectiveness, and ensure availability, the survivability project has sought to incorporate survivability enhancement options (SEOs) at every level of development. This is done within the context of credible baseline and responsive threats, phased deployment of the SDS, and simultaneous defense of multiple systems. The fundamental approach, termed "balanced survivability," uses analysis to determine the optimal combinations of active and passive SEOs that will provide requisite levels of survivability against postulated DSTs.

Accomplishments

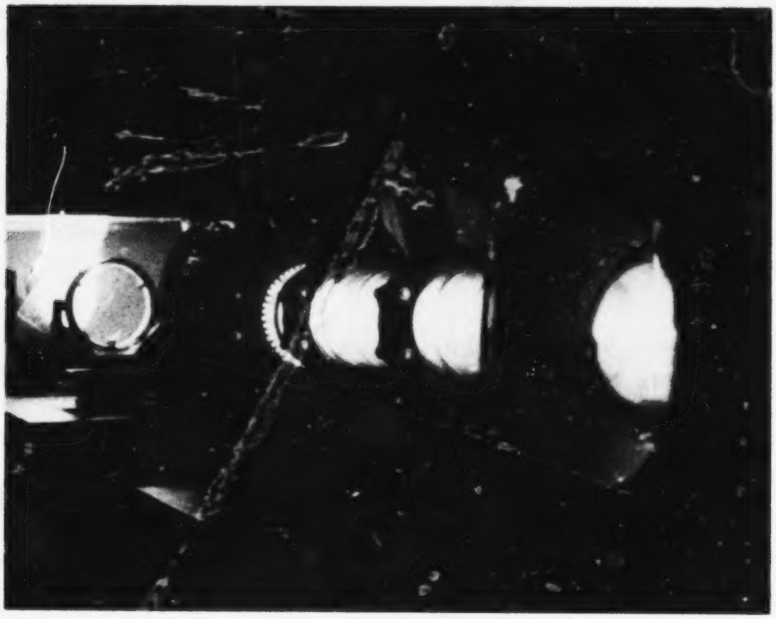
Approximately 70 projects are under way. Significant milestones have been reached in the demonstration and validation of hardened materials and components. These accomplishments will protect SDS assets against laser, kinetic energy, and nuclear threats.

In the defensive shields project, preliminary designs for the Defensive Shields Demonstration (DSD) have been completed. Shield concepts that withstand laser illumination for short periods of time, and pellet impacts, have been demonstrated. These shields not only have capability to withstand these threats but may be applied to spacecraft systems with minimal weight impact.

In support of laser-hardened materials testing, the Laser-Hardened Materials Evaluation Laboratory (LHMEL) has demonstrated high power output (see Figure 6.5-1). Other laser-hardening accomplishments this year include demonstration of a millimeter wave antenna, hardened thermal control louvers, and CERR systems demonstrations.

The hardening and testing of optical components have produced important results. An optics vulnerability data base is being constructed to compile data from demonstration/validation tests. Examination of the survivability levels of optical

Figure 6.5-1
Laser Hardened Materials Evaluation Lab Test



components has led to refinement of analytical techniques. New technology to suppress optical sensor contamination from X-ray induced blow-off has been studied. Component validation by laser testing of components, along the sensor train and external deployable antenna, was conducted for the Advanced Space Systems Hardening (ASSH) Program. In addition, beryllium mirror manufacturing process guidelines were determined.

In support of nuclear hardening, several aboveground tests (AGTs) have been completed, and preparations are under way for underground testing. The first cycle of AGT vulnerability data base development for HgCdTe infrared (IR) detectors has been completed. Also, components needed for Mineral Quarry UGTs have been prepared and tested. Many significant increases have been made in nuclear hardening of components for space- and ground-based elements of SDS. Survivable optics for Air Force systems, including mirrors whose hardness has been significantly increased, have been demonstrated. Beryllium mirrors for Army systems have been demonstrated to survive threat level radiation environments. Optical grade sapphire windows that will survive the nuclear environment are being evaluated for HEDI.

This past year, within the area of the defense suppression threat, the survivability program has provided, and the Phase One Engineering Team has endorsed, the essence of the Soviet defensive threat to SDS. The detailed technical capabilities and, more importantly, the methods by which the Soviets might employ these capabilities against SDS, are documented in the Phase I threat specification for SDS. The DST is specified in two ways, the "design to" and the "evaluate to" threats. "Design to" threats are those threats that the SDS elements must survive. "Evaluate to" threats are specified to test the sensitivity of the design to respond to excursions and to ensure that the design is not near a "threat sensitivity cliff" the Soviets might want to exploit.

Survivability option simulations that are supported by high-fidelity models are now being used for detailed analysis. Model refinement continues to better simulate integrated attacks and to enhance National Test Bed (NTB) simulation capabilities. Together, the outputs of these efforts drive technology development, assist in validating survivability risk, and determine the most favorable survivability approaches.

Future Plans

The FY 1990–91 survivability project efforts are designed to continue and expand earlier work and to progress toward survivability project objectives. The efforts are structured to line up specific technologies for countering projected threats to SDS element needs. This linkage is accomplished through close interaction and coordination with element programs such as GBI. The GBI project is evolving from the Dem/Val ERIS interceptor described in last year's Report to the Congress on SDI.

The FY 1989 efforts are continuing to pursue passive hardening against laser, nuclear, and kinetic threats; active enhancements that will supplement an element's ability to survive the nuclear environments; and operational techniques to help devise employment schemes and policies that will advance the survivability of SDS. Survivability analysis and assessments will continue to help ensure that technology programs are structured to provide the maximum benefit to SDS elements. These analyses will include effectiveness models of space-based systems to ensure that the survivability enhancements proposed are properly balanced to achieve cost-effective survivability at minimum impact to overall system performance. An aggressive program to demonstrate technologies at component and subsystem levels will be pursued as shown in Figure 6.5-2.

The focus of the FY 1989 survivability program is on the applicability of the U.S. efforts to neutralize threats to SDS elements.

A major aspect of the survivability program that will receive increasing attention and funding in the near future is the definition and conduct of the Integrated Survivability Experiments (INSURE) Program. The objective of this program is to take survivability technologies that have been incorporated in element application and demonstrate their effectiveness at or near integrated threat level environments. In a configured mode, as near-operational as possible, these test will show that element survivability is achievable with minimal system impact. The INSURE program will include multiple testing of technology applications including a GBI/GSTS seeker system nuclear test, an integrated laser and nuclear test of a space-based seeker system, and a space flight test of selected technologies.

Figure 6.5-2
Survivability Program Focus Is to Neutralize Threats to SDS Elements

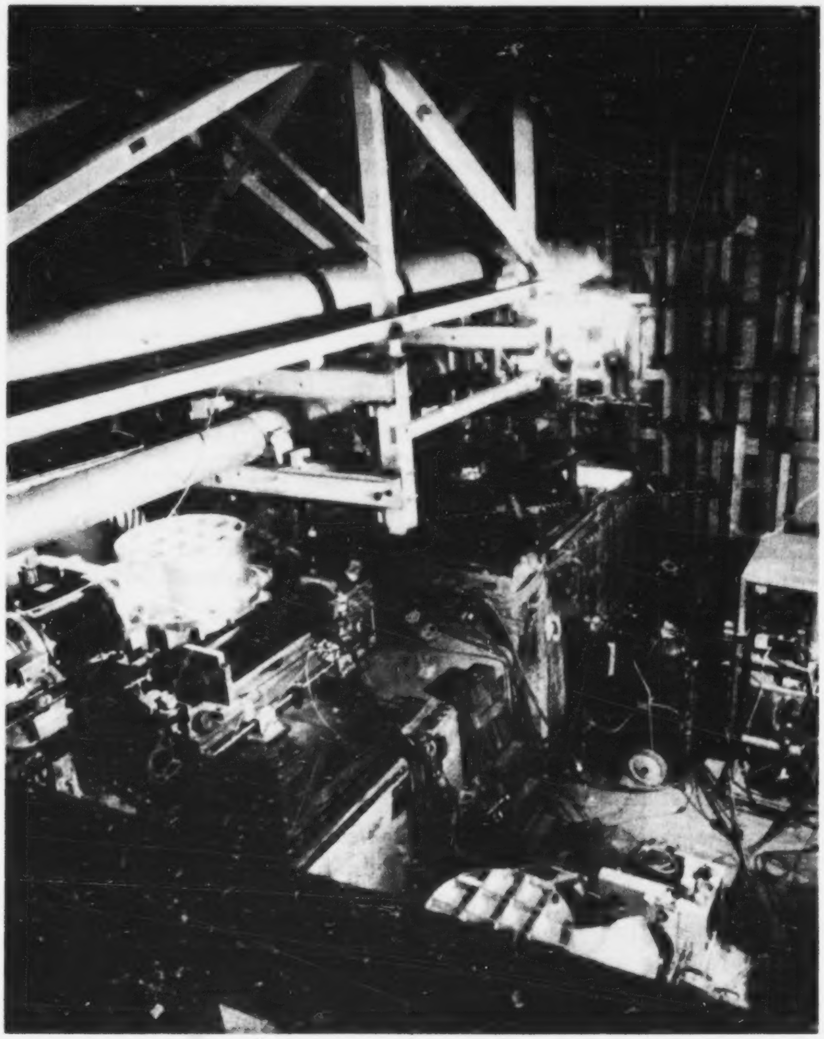
Technology Area	Focus	Applicability
Passive Technology Nuclear, NPB, HPM Kinetic	Hardened Materials, Structures, Shields, Comm, Mirrors, Baffles, FPAs, Windows, Processors, Electronics, Spacecraft Armor	All Elements
Passive Technology Laser	Laser-Hardened Structures, Adhesives, Radiators, Attitude Controls, Insulators— Filters, Rugates, Reflectors, Shields	SBI, SSTS, BSTS
Active Survivability	Tactics, Maneuver, Decoys, ECM, OCM	SBI, SSTS, BSTS
Analysis, Integration, and Assessment	Modeling and Analysis, Balancing Enhancement Suites, Survivability Technology Guidelines, Multiburst Environment	All Elements
Operational Survivability	Rules of Engagement, Space Policy, Survivability Ops, Etc.	All Elements

The FY 1990 program will continue to focus on support of the SDS Phase I technology needs to support the Milestone II decision dates for the elements. Technologies will be transferred as they mature and increasing emphasis will be placed on early demonstrations of technologies as applied to SDS elements. Active survivability measures have demonstrated the ability to provide large increases in survivability, while reducing system requirements for passive hardening in certain situations, for low to moderate investment. This program will identify those measures that can enhance ground-based element survivability, and compare the cost effectiveness to alternative measures. Initial results are required to support System Requirements Reviews (SRRs).

Laser-hardening technologies that are expected to mature during the period include laser-hardened structures, radiators, attitude controls, adhesives, insulation, optical filters, baffles, and limiters.

The AGT/UGT program will see significant activity in FY 1990. Underground tests will test many of the components and designs developed under the technology programs for nuclear effects. Ground- and spaced-based seeker systems will be featured in these tests. To ensure that the UGT will be meaningful and understandable, each proposed experiment will be evaluated in AGT events to characterize the response of the test article and to ensure that its response will be understood in a nuclear environment. Figure 6.5-3 shows a previous UGT test instrumentation configuration.

Figure 6.5-3
UGT Experiment Configuration



A major portion of the FY 1990 program will be devoted to the INSURE program. Integrated test experiments (combined environments) will be used where possible. Flight test programs to demonstrate space environment performance of survivability technologies will be used extensively.

The FY 1990 technology efforts for Phase II systems and threats will identify and develop survivability technologies for the Phase II elements to support a Phase II Milestone I decision. The Phase II system associated with threat changes include an increasing capability in direct-ascent nuclear antisatellite (DANASAT) force numbers and an increasing Soviet ability to locate and track (by radar and optical means) SDS assets. This may also include increased homing ASAT capability in both co-orbital and direct ascent ASATs, along with growing electronic warfare (EW), high power microwave, and NPB capability. Such threats will be included in the technology programs in FY 1990, for both Phase I and Phase II systems.

SDS will require new, well-planned test and evaluation methods. Because it will not be possible to test every subsystem under every imaginable situation, simulation must continue to play a major role in SDS development. Tests that are not feasible to actually perform will be simulated or modeled, utilizing extrapolated "live-test" data.

6.5.2 Lethality and Target Hardening

This section addresses the technology goals, project description, accomplishments, and future plans of the Lethality and Target Hardening (LTH) project.

Technology Goals

The goal of the LTH project is to reduce the uncertainty in our understanding of weapon-target interaction in order to understand what it takes to kill a target. This project also examines weapon and probe target interaction effects and signatures that may be useful for kill assessment and for interactive discrimination of reentry vehicles (RVs) from decoys and space junk.

Project Description

To achieve its technical goals, the LTH project provides confidence data essential to the design of the overall architecture to ensure that individual element performance will meet SDS requirements. It is a comprehensive research effort that studies the damage effects created by SDI weapon concepts and predicts the corresponding susceptibility of Soviet current, retrofit, and responsively hardened targets. The research is focused on the development of materials and techniques for hardening offensive weapons against SDS defenses to determine potentially achievable Soviet performance in this area. The project includes the study of weapon- and probe-target interaction effects and signatures that may be useful for interactive discrimination of reentry vehicles from decoys and space junk, and for kill assessment.

An essential part of the LTH project is the creation and annual update of an integrated lethality assessment document that provides a lethality design handbook for the weapon engineer and the SDS system architect. Through theoretical modeling and appropriately scaled experiments, the mathematical relationships describing weapon lethality, in a manner useful for weapon system design and strategic architecture trade-off studies, is being generated and documented. As the SDI Program in interactive discrimination and kill assessment signatures continues, similar documentation will be prepared.

Accomplishments

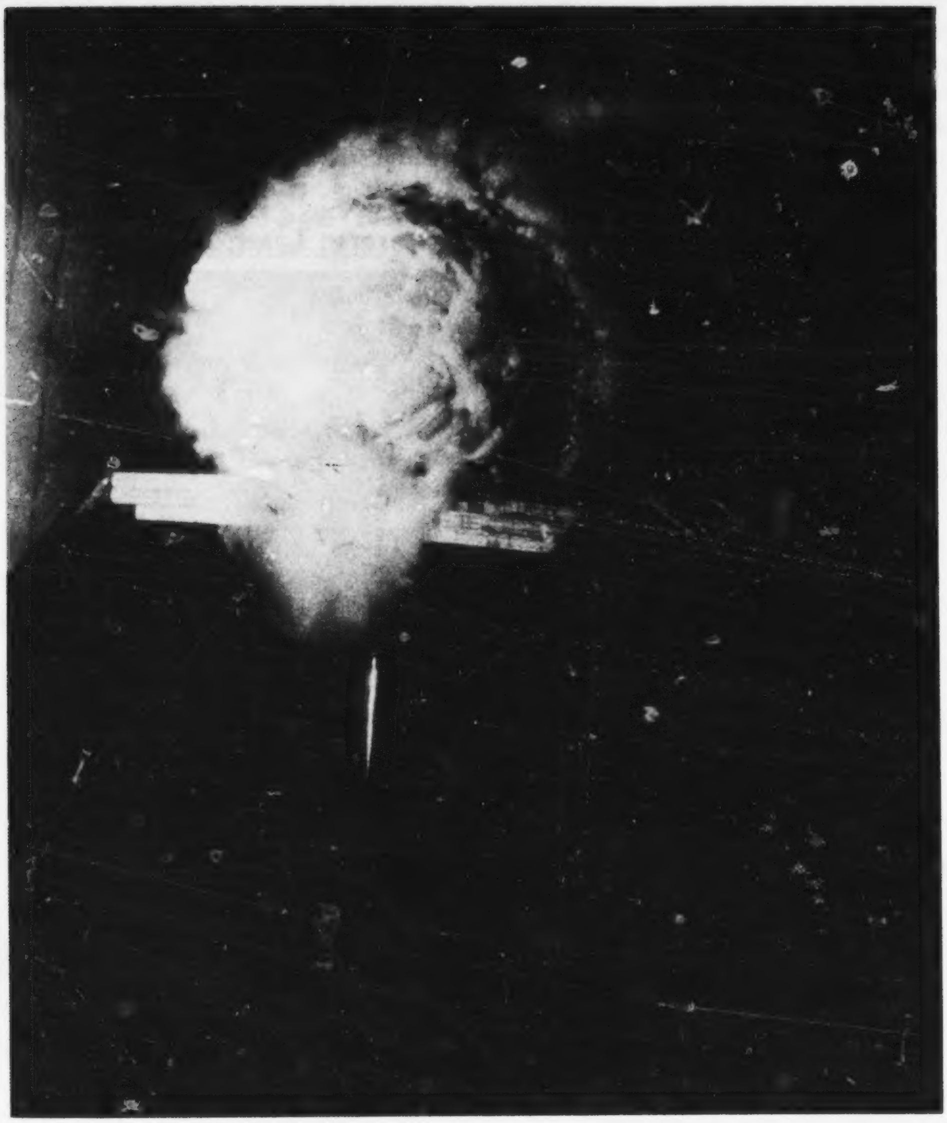
In support of SDS Phase I systems, the LTH project is conducting a number of experiments and analyses that provide essential data required for proper design of interceptor concepts. Recently, during quarter-scale tests representative of a space-based interceptor striking a PBV, it was revealed that significant damage to the structure of the PBV would occur and that the RVs would be displaced (knocked out). However, these experiments were conducted against inert PBVs, lacking not only nuclear materials but also the high explosive that initiates the nuclear explosion and the propellants that thrust the PBV. Under these circumstances, most of the RVs received little or no physical damage. Mission kill of the PBV, in which the RVs would not reach their intended targets, was virtually assured, but it could not be determined whether the RVs would eventually explode at the location where they would fall. Two major programs (the Propellant Initiation Program and the Sympathetic Detonation Program) began in 1988; they determine whether the impact of the interceptor would cause the high explosives and the propellants on board a real PBV to ignite or explode with sufficient energy to render some or all of the RVs incapable of nuclear explosions.

The Propellant Initiation Program has conducted small-scale tests using cylinders and spheres filled with both water and live fuel and oxidizer to provide data for estimating the results of full-scale tests to be conducted in FY 1989. Figure 6.5-4 shows one of the experiments at the moment of explosion of the sphere. The characteristic fragment pattern produced by the explosion, with the fragments riding on the surface of the expanding liquid should be noted. In addition, scaled tests using live fuel and oxidizer were conducted to validate estimates of the energy output from representative fuel and oxidizer tanks.

The Sympathetic Detonation Program is designed to demonstrate whether the detonation of the high explosives in a nuclear warhead, when impacted by interceptors, would "throw" sufficiently large fragments at high enough velocities to detonate the high explosives in the neighboring RVs on the PBV. Due to a "domino effect" (sympathetic detonation), potentially all RVs could be destroyed. Fragment size, fragment mass, and fragment velocity are critical factors in determining the likelihood of sympathetic detonation. As in the case of conventional (non-nuclear) munitions, fragment characteristics are determined by conducting a test in which fragments are collected in a carefully constructed and instrumented environment. To facilitate full-scale testing at non-DOE facilities, non-nuclear materials were substituted for actual weapons components. In FY 1988, a number of small-scale model tests were conducted to select suitable substitute materials that would replicate the response of weapon component materials during an HE detonation. Larger scale tests are scheduled for the near future. Such experiments are essential to the design process of space-based interceptors for use against missiles in the post-boost layer.

The Lethality and Target Hardening Project provides essential support to the SBL/chemical laser program. A large, mature data base of experimental data and lethality assessments has been developed to aid the design of future laser concepts and laser Dem/Val experiments. One potential countermeasure against the laser involves

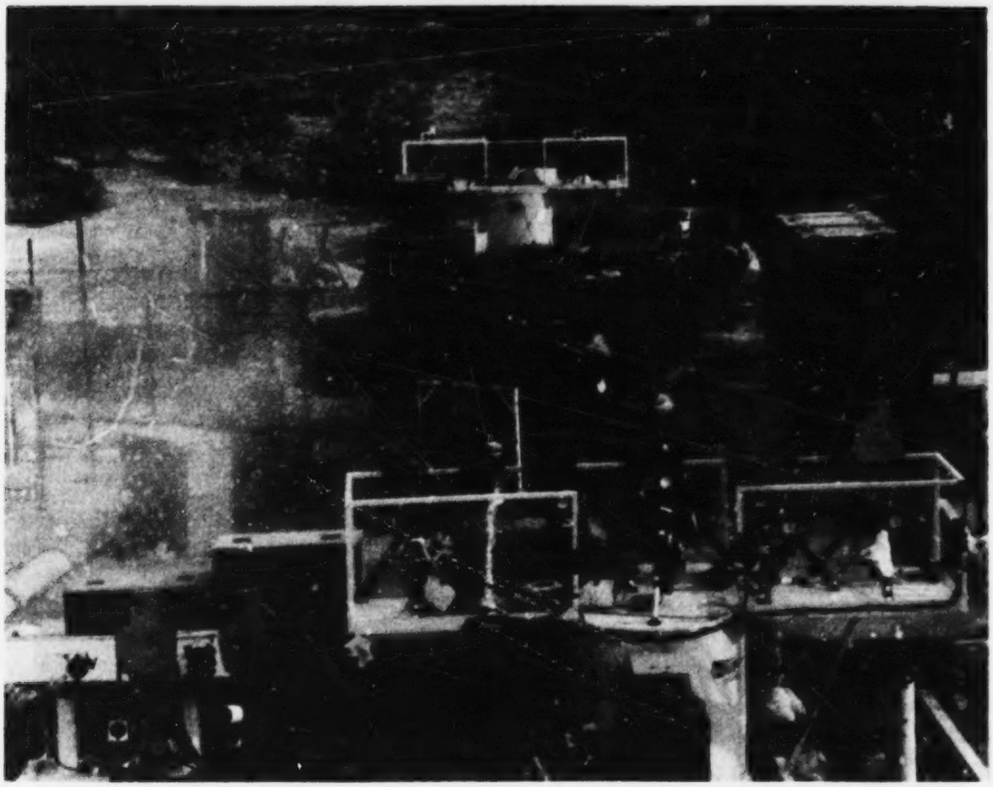
Figure 6.5-4
Propellant Explosion Tests



(1) making the surface of the booster's tank highly reflective and (2) rolling or rotating the booster to distribute the laser energy over a larger area. A series of subscale experiments was conducted at White Sands Missile Range to determine the actual effectiveness of these potential countermeasures. One such test is pictured in

Figure 6.5-5. The test results showed that while such measures might be somewhat effective against lasers of inadequate brightness, they would not be effective against a high brightness laser. Some laser energy is always absorbed because no surface can be made perfectly reflecting. This absorbed energy rapidly destroys the reflection of the metal surface and the damage continues as if the surface had not been polished at the start. For rolling to be effective, the roll rate must be quite high and must be increasingly high as the irradiance on target increases and kill time becomes short. Such high roll rates would be a very significant challenge to a missile design engineer. A planned full-scale experiment has been canceled due to funding limitations.

Figure 6.5-5
Rolling Reflective Countermeasures Laser Test



We have recently completed experiments to compare the damage effects of the radio frequency (RF) linear accelerator (linac) free electron laser (FEL) with those of the induction Linac FEL. Analysis of these experiments is in process. The results of these and similar experiments are essential to deciding whether an operational FEL weapon should be designed with an RF Linac or an induction linac, and what its specific performance parameters should be. We are planning for lethality effects tests to be included with GBFEL experiments planned for WSMR.

The experiments and tests of the LTH project are performed at a number of facilities. For example, thermal laser testing is accomplished at the DOD High Energy Laser Systems Test Facility (HELSTF) at WSMR, New Mexico. A large vacuum chamber has recently been constructed at HELSTF and is being used for a variety of survivability, lethality, and interactive discrimination experiments in an environment that simulates the vacuum of outer space. The Brookhaven National Laboratory Radiation Effects Facility on Long Island is a workhorse in neutral particle beam effects testing. A neodymium laser at Battelle National Laboratory in Ohio provides waveforms suitable for effects simulation of the free electron laser. This laser, currently being upgraded, at a cost of $0.4 million, will provide a pulsed laser test facility until the Ground-Based Free Electron Laser (GBFEL) experiment at WSMR, which is part of the Directed Energy program, comes on line. As noted earlier, the LHMEL at the Air Force Materials Laboratory in Dayton, Ohio, which is used for testing small samples of hardened materials, is also being upgraded at an FY 1988 cost of $3.2 million.

The LTH project is conducting a number of experiments and analyses in support of NPB weapon concepts. The ability of the NPB to destroy electronic systems in RVs, PBVs, and boosters has been investigated. The susceptibility of high explosives and propellants have also been studied. This testing was conducted at the NPB lethality test facility in Brookhaven, New York. Testing has shown the NPB capable of destroying the electronics and high explosives. Discrimination work in the NPB area has entailed measuring particle returns from decoys and RVs to distinguish between the two.

During FY 1988, SDIO spent $10.0 million toward the development of the Strategic Defense Facility at Sandia National Laboratories. This facility is jointly funded with the Department of Energy and will provide the capabilities to conduct experimental research in particle beams, X-ray lasers, and accelerated projectiles and vulnerability/lethality effects tests.

Future Plans

The Propellant Initiation Program and the Sympathetic Detonation Program will conduct large-scale tests in FY 1989. These tests will verify predictive capabilities and provide important answers to KE Phase I systems as well as follow-on systems.

Ground testing and preparation for flight tests to verify levels of damage necessary to induce aerothermal demise of RVs will be conducted in FY 1989. A lethality test will occur in FY 1990.

The lethality project is supporting the major kinetic energy weapon experiments, i.e., ERIS, SBI, and HEDI, by assisting in planning the lethality elements of these tests. Support is also provided to the Invite, Show, and Test project of the theater missile defense program.

To date, calculations have been required to extrapolate the results of low velocity KEW impacts to higher velocities. These calculations are uncertain, however, and test facilities are required to experimentally verify the calculations. It is possible that higher velocities could induce less damage for some engagements. Future plans call for LTH to utilize the Thunderbolt facility for high velocity testing when it becomes available.

Future research will seek to identify lethality enhancers which will increase effectiveness. At the same time lethality efforts will seek innovative hardening schemes and ensure that the projectiles used by SDS are capable of overcoming them.

During FY 1989, the thermal laser lethality program continues with high intensity testing of hardened materials and other hardening concepts. We will also provide support to the Zenith Star program by assisting in the design of targets. In FY 1990, the technology program will shift into examination of PBVs, decoys, and defense suppression weapons, including characterization of the discrimination signatures of decoy materials.

Completion of the assessment of NPB lethality against unhardened post-boost vehicles and reentry vehicles in FY 1989 is projected. In future years, we will begin testing of advanced electronics, and will investigate the performance enhancements that might be possible through the use of heavier particles, such as helium and lithium atoms, for the beam. In support of NPB interactive discrimination concepts, we will be testing a decoy designed to foil this technique. Experiments and analyses to characterize the neutron return signatures from a variety of midcourse targets will continue.

6.5.3 Space Power and Power Conditioning Projects

This section discusses the technology goals, project descriptions, accomplishments, and future plans of the space power and power conditioning projects.

Technology Goals

The success of nearly all elements of an SDS depends upon major advances in the areas of prime power generation and conditioning technologies. Sources capable of generating the necessary power will be required to operate reliably, while concurrently meeting constraints pertaining to size, weight, life-cycle costs, and survivability. The Space Power and Power Conditioning program supports all SDS Phase I and follow-on elements. For elements requiring only baseload power, the program includes survivable solar power technologies to support the modest power needs of the Phase I space-based elements, with growth to higher power levels for Phase II accommodated by the SP-100 nuclear reactor technology. For Phase II elements requiring burst power, the program addresses development of advanced power systems through the non-nuclear and nuclear multimegawatt programs for space-based elements, and Superconducting Magnetic Energy Storage (SMES) for ground-based DEW elements. The SDI power program is structured in four general categories: baseload power, multimegawatt technology, pulse power and power conditioning, and requirements and analyses.

Project Descriptions

The Phase I space-based systems (BSTS, SSTS, SBI) will need continuous baseload power (a few kilowatts to a few tens of kilowatts). Although this represents a modest extrapolation beyond our existing experience base, the power systems for these applications will have to be survivable in the face of hostile defense suppression threats. Specifically, the baseload power system will have to be hardened against nuclear, laser, and pellet threats.

To address these survivability requirements, the Survivable Concentrating Photovoltaic Array (SCOPA) project is providing demonstrations of fundamental survivability technologies. One of the SCOPA concepts is shown in Figure 6.5-6. Building on the background gained from SCOPA, the Survivable Solar Power Subsystem Demonstrator (SUPER) will establish the baseline solar power technology necessary for Phase I deployment. Extensive ground testing for survivability will precede a space qualification flight test. Technology development programs for batteries and other supporting solar power conditioning systems are also in place to ensure reliable, long-life, lightweight systems.

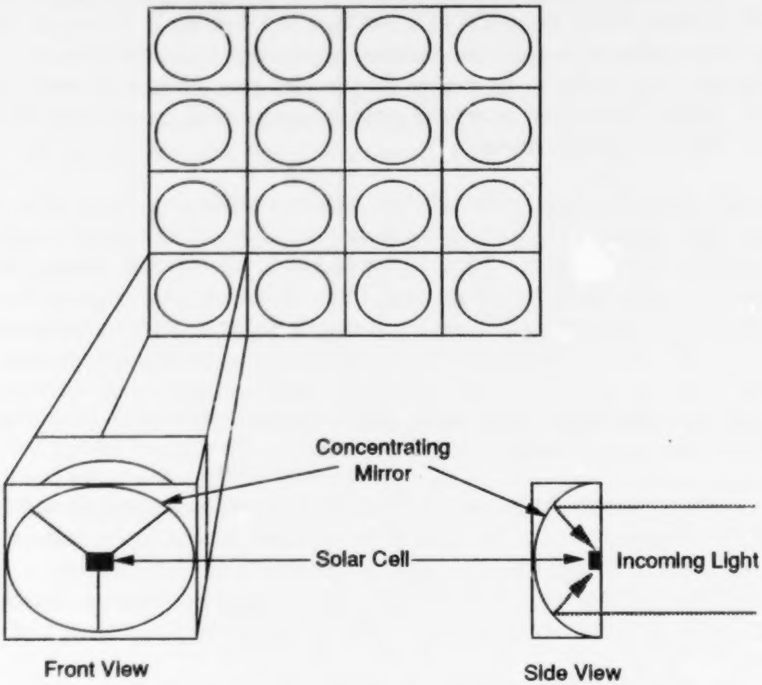
Energy storage batteries for solar power systems are subjected to thousands of charge/discharge cycles as the orbit of the satellite passes through the earth's shadow. In comparison to solar power at geosynchronous altitudes, the batteries in low earth altitudes must meet more stringent requirements, being subjected to shorter charge/discharge times and a larger number of cycles over the course of a 7- to 10-year lifetime.

A major project of the requirements and analysis thrust will characterize and compile into a comprehensive design tool the natural, induced, and hostile space environment parameters that have a bearing on the design of power systems.

The emergence of the Phase II elements will usher in the need for increased levels of baseload power (tens to hundreds of kilowatts continuously throughout the on-orbit life of the system). For the first time, there will be a need for burst power sources capable of providing tens to hundreds of megawatts for hundreds to thousands of seconds in order to power electrically driven directed and kinetic energy weapon systems, as well as for support for numerous pulse power and high capacity power conditioning technologies.

To meet the requirements for baseload power, space nuclear power becomes the technology of choice because of its mass advantage over scaled-up survivable solar schemes as well as its inherent hardness capability. Hardness considerations are particularly important in light of increasingly oppressive DSTs. The SP-100 space nuclear reactor program is focused on meeting these power and survivability requirements.

Figure 6.5-6
SCOPA Concept



Multimegawatt burst power is required to power weapons and active sensor systems during engagement. The development of both nuclear and non-nuclear multimegawatt burst power technologies is under way to support the space-based SDS power requirements. During FY 1988, $3.4 million was spent to upgrade the Army's pulse power center to support full power evaluation and life-cycle tests on multimegawatt components associated with directed energy weaponry, electromagnetic launchers, and high-power sensors (radar).

Ground-based defensive systems such as the ground-based laser (GBL) will require power levels much greater than space-based systems. An effort to develop SMES has been initiated with the goal of establishing the feasibility of this technology to provide more efficient and reliable power to the GBL. Because SMES also holds great promise for utility load leveling applications, it is partially funded by the Electric Power Research Institute (EPRI).

Pulse power and power conditioning technology development is required to transform the electrical characteristics of the prime power source to match the requirements of the weapons and sensor systems. These components and systems include high power RF sources needed to energize power accelerators, energy storage devices, high power switches, and other power conditioning devices.

Accomplishments

Tests to measure sample of SCOPA concentrator mirror performance, under high intensity nuclear weapons effects, were initiated in 1988. These tests provide important fundamental solar array survivability information. Samples that were subjected to preliminary reflectance measurements performed with less than 5 percent degradation in reflectance.

Initial designs for SUPER have begun. This project will provide baseload power technology capabilities. Efforts to integrate SUPER with the orbital maneuvering vehicle (OMV) have been made to provide for a low-cost space qualification flight.

High energy density batteries are required for all SDS elements. Competing programs have been established to develop and demonstrate electrochemistry technology options. Specific designs have been defined, and experimental battery units are being built. Electrical and mechanical testing will verify the designs so that the best candidate technology can be selected.

A program to develop a lightweight, high energy density, rechargeable battery has demonstrated an enabling technology that would allow greater than 5KW of solar power at geosynchronous orbits at substantial cost savings. Another program that is focusing on very high cycle life batteries is in the process of testing and validating experimental cells.

An Environment-Power System Analysis Tool (EPSAT) development program is being developed with the goal of providing a computer-aided design/engineering (CAD/CAE) tool for space power system designers. Generalized power system descriptions have been incorporated into computerized data base environment models that are anchored to space flight models in order to begin an analysis of power system-environment interactions. A Solar Array Performance in Plasma Environments (SAPPE) tool has been completed that models the electrical interaction of flat solar arrays in the space plasma. The models have been targeted to space flight data. To address the issue of power system effluents, a streamlined set of computer algorithms was created to enable the determination of density profiles for neutral effluents surrounding high power SDS platforms without expending enormous amounts of supercomputer time.

The SP-100 Ground Engineering System (GES) plant demonstration project made significant progress by completing preliminary preparation of the test site at Hanford, Washington. Procurement for long-lead items such as test equipment was begun, and final design of the test apparatus is under way. Fuel for the reactor is in full production and delivery of fuel pellets to the site has started. A Systems Design Review of the SP-100 flight system was completed with approval of the design contingent on only minor changes. Subsystem component design efforts have moved to the prototype testing phase for such items as reactor control drives and latches.

The refinement of nuclear multimegawatt concepts was initiated with competitive awards to 6 contractor teams for 1-year concept development studies. Both open and closed cycle systems are being considered. Midterm reviews of the study efforts were conducted at the end of FY 1988 and each contractor team showed commendable progress.

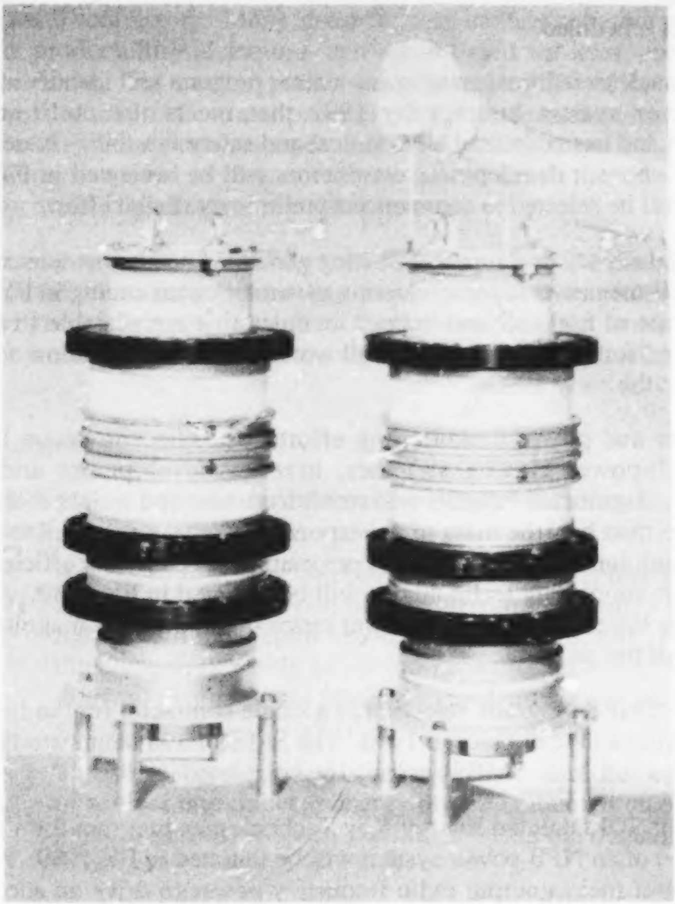
The non-nuclear multimegawatt development program has realized significant advances in fuel cell technology as well as rotating machine and superconducting generator technology. For example, testing of a subscale prototype for the high power density fuel cell program indicated that a full-size module demonstration would exceed the original power density goals. A manufacturing development program for long lengths of superconductors has improved the current carrying capability of the superconductors in high magnetic fields. Research on current collection at cryogenic temperatures has been able to identify unique material and thermal design characteristics that will advance the development of lightweight homopolar generators.

The SMES program, which began in FY 1988, has already completed a feasible, detailed design of the superconductors. A superconducting transformer and a superfluid helium refrigerator have been constructed to test superconductor configurations. Cryogenic tests of structural and thermal insulating materials have been performed to determine physical performance. An initial assessment of candidate sites for the Engineering Test Model (ETM) has been completed. The enthusiastic response from candidate host electric utilities for the ETM has reinforced the confidence in its utilization.

Major advances in the pulse power and power conditioning area occurred in FY 1988. A lightweight klystrode, which provides the RF power to drive a weapon accelerator, was tested at the 500 kilowatt level. Advances in this area are rapidly approaching the power levels required for an operational NPB accelerator. The demonstration of a competing technology, a solid-state radio frequency amplifier, at cryogenic temperatures has significant implications for power conditioning system mass reductions. A high voltage, megawatt-average power thyratron switch was operated, implying a significant cost reduction for the GBFEL TIE by enabling a simplified power conditioning scheme (see Figure 6.5-7). Dramatic reductions in energy storage capacitors are evident. Research in the area of semiconductor MOS-controlled thyristors has also shown promise for spinoffs in the development of electric drives useful for advanced military tanks and commercial automobiles.

A study to evaluate the performance gains through the use of nuclear reactors in place of the baseline solar arrays on an SSTS platform has determined that nuclear reactor power sources can offer significant survivability advantages.

Figure 6.5-7
High Voltage Thyratron Switch



Future Plans

Both SCOPA and SUPER solar power development programs will continue as an alternative survivable baseload power technology options. Laser and radiation hardness testing of the SCOPA concepts will be completed in FY 1989. Downselection of SUPER detailed design concepts will occur in FY 1989, with component development and ground-based testing scheduled to be complete by FY 1992 prior to a space qualification flight test.

Battery demonstrations for interceptors will be complete in FY 1989. After a downselect, another design phase to refine the battery system to meet particular weapon requirements will be followed by an advanced technology program.

Future efforts in the SP-100 program will be focused on the continued fabrication of the fuel and the prototype unit. Test facility modifications will proceed and the prototype will be installed in the test facility for a 1994 demonstration. Following successful Dem/Val testing of the SP-100 prototype, a reactor space flight experiment is scheduled.

The nuclear multimegawatt space reactor program will identify at least one space nuclear power system concept by 1992 that meets the multimegawatt power requirements and has addressed all technical and safety feasibility issues. Final reports from the six concept development contractors will be reviewed in FY 1989 and two contractors will be selected to commence a preliminary design effort.

The feasibility of a superconducting generator will be demonstrated by no-load testing of a 20-megawatt superconducting generator commencing in FY 1989. Several demonstrations of fuel cell and battery modules that are scalable to the high-power levels required for SDS applications will occur in FY 1989 to allow for a technology downselect in the early 1990s.

Power and power conditioning efforts will concentrate on high-power RF sources, high-power closing switches, inverter development and other related technologies. Significant benefits will result from size and weight reduction advances because more than half the mass of a weapons platform is expected to be attributed to the power conditioning components. A program to develop high efficiency, megawatt-level inverters supporting technologies will be initiated in FY 1989. A goal has been established to lower the weight-to-power ratios by an order of magnitude beyond the present state of the art.

In the SMES program, selection of a single contractor for the final ETM design and construction will take place in 1990. The SMES ETM demonstration is scheduled for 1994 with a full-scale SMES design to be completed in 1995.

A joint SDI Directed Energy-Key Technologies program for a ground test and demonstration of an NPB power system will be initiated in FY 1989. An entire power train from input fuel to output radio frequency power to drive an accelerator will be constructed and demonstrated in the early 1990s. Confidence in the multimegawatt technologies used in the NPB demonstration will reach the medium level. High confidence will be reached by addressing space-specific issues such as effluent management and integrated platform dynamics.

6.5.4 Materials and Structures Project

This section addresses the technology goals, project description, accomplishments, and future plans of the Materials and Structures (M&S) project.

Technology Goals

The goal of the Materials and Structures (M&S) project is to provide critically needed advances in materials and structures technologies for Phase I and follow-on phase SDS elements to assure performance capabilities, affordability, and reliability. Materials and structures technologies provide an essential base of technology that supports and underpins SDS high performance ground- and space-based systems. Needed advances are determined through close and continuous coupling with SDIO system offices and contractors. M&S research goals include reducing weight and cost and increasing producibility of ground- and space-based vehicles, enhancing sensor tracking and weapon fire control performance, assuring long-life space platform moving mechanical assemblies, and providing high performance components using newly discovered high temperature superconductivity (HTS) materials. Development of these advances is paced to assure their timely insertion into the SDS element acquisition process at critical decision points.

In meeting its goals, the M&S project builds on the materials and structures technologies of the entire nation, providing a technology conduit linking the materials and structures research community to SDS element program needs. The project accelerates the transfer of research laboratory advances into practical devices for SDS applications.

Project Description

The M&S project addresses critical materials and structures technology needs in six major areas of research.

- Advanced structural composites, including graphite-reinforced resin and metal matrix composites required to provide small and lightweight interceptor kill vehicle structures; stiff, lightweight and dimensionally stable precision structure elements for sensor and directed energy space platforms; and strong but readily fabricated structures for high production rate spacecraft.
- Structures control technologies required to achieve precision pointing of sensors and directed energy devices mounted on lightweight and inherently flexible space platforms during the dynamic environment of battle.
- High temperature superconductivity (HTS) components for IR detectors that provide broad spectrum capability and significantly reduced cryogenic cooling requirements on space sensor platforms, high performance millimeter wave communication components, and low-loss RF cavities that can significantly reduce NPB and FEL power and weight requirements.
- Tribological system materials that will extend life, precision, and reliability of space platform moving mechanical assemblies such as sensor gimbals, control moment gyros, reaction wheels, and cryocoolers.
- Power and thermal management systems materials that reduce weight or enhance on-orbit performance of power generation devices and

improve survivability and reduce weight of space platform thermal management components with emphasis on thermal radiators.

- Qualification of space platform materials to withstand atomic oxygen, the charged particle and ultraviolet radiation and debris environment of SDS orbits for on-orbit lifetimes greatly exceeding current spacecraft experience.

Accomplishments

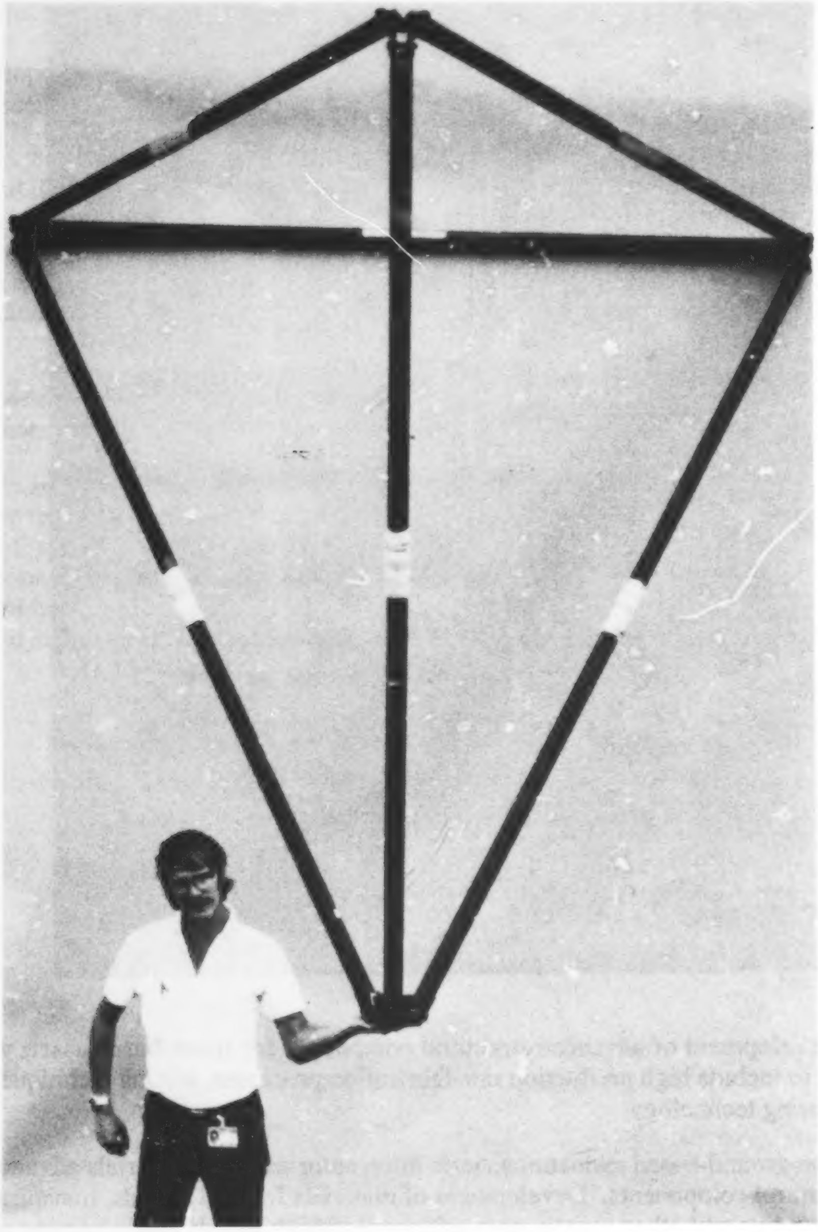
Numerous major efforts have continued since the last report and the most significant accomplishments in the past year in support of both Phase I and follow-on phase SDS are summarized below.

- An active space materials experiment, the first of its kind, has been mounted on SDI's Delta Star.
- A passive damping material has been space-qualified and applied to the RME flight structure to reduce launch vibrations. This important technology development will be applied to several SDS elements.
- Interceptor sensor window strength under bending loads has been doubled using ion implantation and non-contact polishing techniques.
- In a joint activity with NSWC, a lightweight truss structure representative of DEW platform requirements has been fabricated using a graphite aluminum composite and its high inherent stiffness verified by test (see Figure 6.5-8).
- An experimental KKV structure representative of an ERIS flight test vehicle was fabricated from an advanced resin matrix composite. It was 42 percent lighter than its ERIS counterpart (see Figure 6.5-9).
- Seven contract teams consisting of experts from universities, industry and federal laboratories have initiated efforts to demonstrate in 30 months, proof-of-concept IR focal plane array sensor and millimeter-wave components using high HTS materials.
- The integrated structures model (ISM) being developed to predict the performance of space platform structures in the dynamic environment of the SDS has been experimentally applied to current spacecraft designs, verifying utility and reduced computing time.

Future Plans

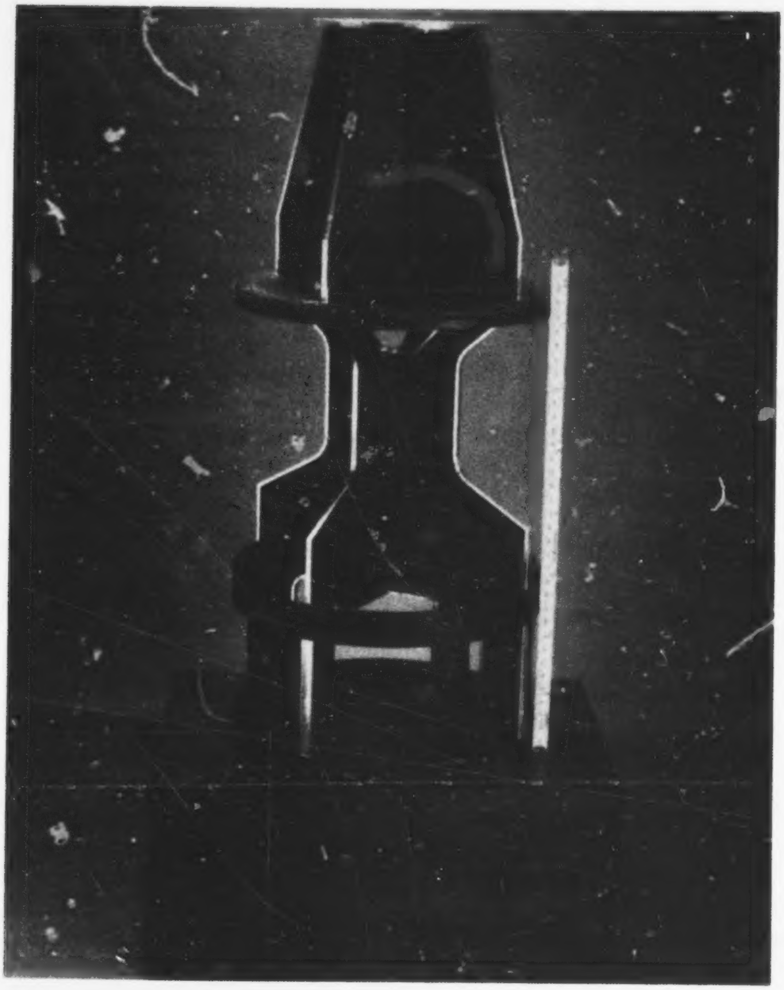
Major developments and test events for FY1990–91 will provide advancements essential to the effective and timely infusion of technologies into Phase I and future systems. Technology demonstrations of materials and structures advances involving SDI system prime contractors will be accelerated. These demonstrations include (1) space surveillance platform sensor gimbals using long-life tribological materials, (2) a lightweight composite thermal radiator, (3) space platform structural truss segments

Figure 6.5-8
Lightweight Truss Structure



made of lightweight and high production rate graphite reinforced thermoplastic composites, and (4) advanced lightweight and stiff interceptor kill vehicle structures and components designed to representative flight requirements.

Figure 6.5-9
Experimental KKV Structure



Development of advanced structural composites for space-based assets will be expanded to include high production rate fabrication processes, joining techniques, and manufacturing technology.

The ground-based endoatmospheric interceptor requires materials advances for thermal control components. Development of materials for heat shields, transpirational cooled nose-tips and other components subjected to high aerodynamic heating will be accelerated.

Achieving a stable and precision structure for DEW space platforms in the extreme dynamic environment encountered during battle will require a precise mix of passive damping, active damping, and structure shape control. The existing PACOSS dynamic test hardware will be modified to extend damping research to include advanced active damping techniques and development of optimum damping algorithms. Development will be continued of the integrated structures model (ISM) for use by space sensor and weapon pointing performance.

Plans are being prepared to provide structural materials for the SBL SPICE ground demonstration, Zenith Star flight experiment and the Pegasus flight experiment. Advanced structural composite developments will be continued to provide lightweight and stiff materials for application to large precision truss structures for NPB and SBL beam expander structures. Development of tribological materials for precision moving mechanical assemblies on space platforms will continue as well.

Development of high-performance, high-temperature superconductivity (HTS) components for space platforms will be continuing toward key proof-of-concept tests scheduled for the FY 1990–91 timeframe.

A ground and space test program being undertaken in cooperation with NASA will be expanded to determine the effects of the natural space environment on the useful life of space-exposed materials and develop solutions to identified life-limiting environmental interactions. SDIO activities will emphasize testing of materials of critical importance to SDS. Extensive use will be made of existing space environment ground simulation facilities, limiting the requirement for expensive space testing.

Section 6.6

Space Transportation

6.6 Space Transportation

This section describes the technology goals for space transportation activities, their accomplishments, and future plans.

6.6.1 Technology Goals

The deployment, assembly, maintenance, and servicing of a strategic defense system will require a substantially increased space launch capability. Based on the results of architectural studies conducted over the last few years, the current focus of the SDIO Transportation program is the Advanced Launch System (ALS). The objective of the ALS is to satisfy launch requirements of all users, including DOD, NASA, and national sectors by the year 2000. ALS has a goal of reducing by a factor of 10, as compared to the present Titan IV, the cost of delivering cargo to low earth orbit. The optimum ALS will be determined at the Milestone I DAB review scheduled for 1990.

6.6.2 Project Description

The ALS program includes definition of the vehicle, demonstration of technologies to meet program goals, and an evaluation of current operations practices. Technologies to be demonstrated include propulsion, avionics, structures, aerothermal protection, and operations, as shown in Figure 6.6-1.

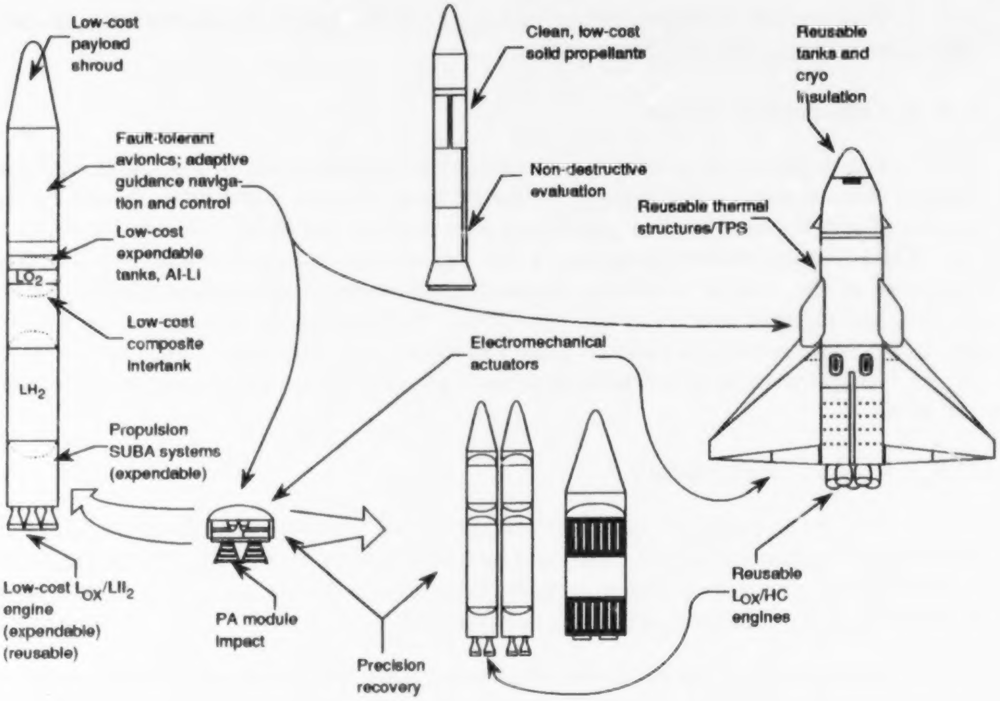
Alternate space transportation architectures are being examined in the event that the ALS is not ready for deployment with the initial elements of the SDS, or if an alternate architecture proves to be more cost effective for SDS Phase I components. Alternatives include, but are not limited to, expansion of existing systems, development of new dedicated launch vehicles, or some combination of the above.

The ALS program is a joint DOD-NASA effort. Technology programs are coordinated among the SDIO and other DOD and NASA agencies. Daily management of the ALS program is conducted through a joint DOD-NASA ALS Program Office at the Air Force Space Division. The Joint Program Office makes the best use of both Air Force and NASA expertise and facilities.

6.6.3 Accomplishments

Since the last Report to the Congress on SDI, seven ALS Phase 1, Concept Definition, contracts have been awarded and the work completed. Three of these contractors were selected to continue into Phase 2, Concept Validation. These assignments are to be completed 25 months from contract start. A Focused Technology Plan was developed by SDIO, NASA, and the Air Force, and work is progressing in accordance with this coordinated plan. An approved Mission Element Needs Statement (MENS) for ALS was coordinated in August 1988 by the Joint Chiefs of Staff and became the basis for a successful Defense Acquisition Board Milestone 0 approval in November 1988.

Figure 6.6-1
Advanced Launch System Vehicle Technologies


Low-cost payload shroud
Fault-tolerant avionics; adaptive guidance naviga-tion and control
Low-cost expendable tanks, Al-Li
LO_2
Low-cost composite intertank
LH_2
Propulsion SUBA systems (expendable)
Low-cost L_{OX}/LH_2 engine (expendable) (reusable)
PA module impact
Precision recovery
Clean, low-cost solid propellants
Non-destructive evaluation
Electromechanical actuators
Reusable tanks and cryo insulation
Reusable thermal structures/TPS
Reusable L_{OX}/HC engines

Future Plans

In the next year, the following technologies will be receiving emphasis: low-cost LOX/H_2 engines, clean low-cost solid propellants, expert system applications, vehicle health monitoring, cryogenic tanks, ground operations, and manufacturing technologies.

Preliminary design of the components of the LOX/H_2 engine and components of the vehicle health monitoring system should be defined by mid FY 1989. The manufacturing process demonstration and the improved formulations for solid propellants should occur in late FY 1989.

The ALS DAB Milestone I review is currently scheduled for March 1990. Milestone I will approve a specific ALS vehicle design for development. Current schedules call for an initial ALS flight in 1998 with IOC in 2000.

Section 6.7

Innovative Technologies

6.7 Innovative Technologies

This section describes technology projects and plans for future efforts in two special programs: Innovative Science and Technology (IST) and Small Business Innovative Research (SBIR).

6.7.1 Innovative Science and Technology

This section describes the IST program's technology goals and its accomplishments and future plans.

Technology Goals

The IST program is that part of the technology base effort that encourages prompt exploration of new initiatives. As such, its goal is to exploit innovative technologies seeking "breakthroughs or quantum leaps" that would improve the capability of an SDS to perform its specific assigned functions.

Project Description

This program provides funds for advanced research in fundamental science and engineering focusing particularly on exploitable technical areas applicable to ballistic missile defense. The IST office sponsors fundamental research programs in six major thrust areas: (1) advanced high-speed computing, (2) materials and structures for space applications, (3) sensing and discrimination, (4) advanced space power, (5) advanced propellants and propulsion, and (6) directed/kinetic energy concepts. This sponsorship, which is limited by available funding to a relatively small portion of potential participants, is exercised and carried out by 40 science and technology agents. These agents, in turn, enlist the services of innovators in as many different scientific areas. Basic research results gathered under this program are structured to expand the forefront of science and technology, with ultimate transfer of such results to tasks in other SDI Program elements.

The IST research effort is conducted throughout the scientific community in universities (including those with a significant ethnic or minority student population), government and national laboratories, small businesses, and large industries.

Accomplishments

Already the concerted push described above has resulted in these accomplishments:

- Made monocrystalline diamond films on metallic substrates.
- Accelerated objects to 6 kilometers per second.
- Measured invisible high atmospheric clouds having critical implications for laser beam propagation.

- Determined the insulating properties of the low earth orbit space environment.
- Predicted ICBM telltale ultraviolet radiation.
- Invented a cryocooler gas mixture that septuples infrared sensor cooling rates.
- Grew a new superlattice that protects optical detectors from light overdoses.
- Used a laser to paint copper conductors on a substrate to reduce electronics packaging.
- Grew very thin silicon layer on gallium arsenide to thereby reduce power loss by two-thirds.
- Made a superconducting Josephson Junction at 15°K to enable a voltage-tunable Terahertz oscillator.
- Employed atomic layer epitaxy to make the thinnest, most highly strained quantum wells ever reported.
- Tripled second-order nonlinearity of optical materials to enable optical shutters and computing activity.
- Created a light spot below the equivalent diffraction limit using near-field scanning optical microscopy.
- Discovered a bacterial protein capable of optical computer switching to mimic a human neural net.
- Demonstrated a fiber optic gyroscope at 77°K (this could enable interceptor control on the back of the focal plane).
- Made an accelerometer (more compact than ever before) by adapting scanning tunneling microscopy principles.
- Linked 1.5 GW microwave sources in a phased-array precursor (this could greatly multiply power levels for beams projected into space).

Future Plans

The search for highly innovative technologies will continue. Funds will be invested as high-payoff opportunities arise in the rapidly moving fields of technology around the world. Specific projects to benefit from present opportunities may be noted in the following:

- Develop a Superconducting IR Detector which would operate in the 2 to 20 micron region and produce a 1,000-fold reduction in cryocooler weight, the promise of responsivity exceeding HgCdTe, the ease and economy of niobium (metal, not semiconductor) fabrication, and high resolving power with small aperture. The critical step is to develop the back-of-the-focal plane readout electronics monolithically with the superconducting FPA, and to merge them with miniature three-stage refrigerators. (Time: 3 years)

- Develop the first diamond metal semiconductor FET using the radio frequency plasma-enhanced chemical vapor deposition process developed for growing monocrystalline, semiconductor-quality, thin-film diamond. SDI and the electronics industry would get refractory microelectronic devices suitable for high-speed switching of electrical power in the microwave and millimeter-wave region, enabling low-weight, solid-state circuitry for communications and radar. The critical step is to provide an industrial device fabrication facility devoted to exploiting IST's film-making capability. (Time: 3 years)
- Demonstrate a lightweight Digital Optical Computer prototype of arbitrary bit length, suitable for space-based platforms. The expected performance is equivalent to 10^4 VHSIC chips (10^{15} gate operations/sec) with power consumption of 100 w, or 2 to 3 orders of magnitude improvement in performance at the same power. SDI will get a drastic reduction in weight and power for on-orbit signal and data processing, while speeding the transition from digital to analog processing of signals. This technology is available now.
- Develop an advanced Lightweight Guided Projectile weighing less than 500 grams but with the same accuracy of larger interceptors. SDI could adopt it for SBI, Brilliant Pebbles, HEDI, and ERIS. Electromagnetic launchers will benefit in the reduction of the prime power supply weight for the space platform, as well as a 20 km/sec projectile to make the EML a cost-effective candidate for fast-burn booster defense. The key issues are (1) guidance and control, (2) seekers, (3) divert motors, and (4) structural components. (Time: 2 years)
- Demonstrate Intersatellite Laser Communication in the laboratory by exploiting the latest technology. SDI will get a clear demonstration of a system which is inherently jam resistant, has a high data rate, is lightweight, and has lower power needs. The key issues are the exploitation and integration of new technology in (1) atomic line filters, (2) wide field-of-view acquisition, (3) multichannel subcarrier modulation of the laser beam, and (4) 2 to 3 Gbps data rate with doppler immunity. This experiment includes 15 nodes to emulate a realistic SDI communications network. (Time: 3 years)
- Perform design trade-off analyses for structural components fabricated using Microstructurally Toughened Composites. These are applicable to design and construction of components such as mirror supports, missile casings, antenna structures, composite joints, and heat exchangers having enhanced survivability, greater toughness, and greater economy. The key issues are (1) the design of components using this technique, (2) the actual construction of leading candidates, and (3) testing and evaluation. (Time: 3 years)

- Demonstrate Phased-Arrayed High-Power Microwave Sources with scalability to large numbers of sources. This applies to large-scale power transmission from earth to LEO, MEO, and GEO and high lethality levels for midcourse interception. The key issue is whether a coherent phased array of magnetrons can be scaled up to 6 or more devices. Two 1.5-gigawatt sources have already been demonstrated. (Time: 2 years)
- Develop Atomic Layer Epitaxy as an industrial process for producing large-scale GaAs integrated circuits. This could yield high throughput and rad-hard circuits using VLSI, applicable to signal and data processing. The key issue is to transfer the university know-how to a large industrial chip manufacturer. (Time: 2 years)
- Develop silicon-oxide-nitride-oxide-semiconductor (SONOS) technology for nonvolatile memory. SDI would thus fill a need for 14 million 24-bit words per satellite to replace the presently used magnetic tape. No other emerging nonvolatile memory technology is likely to achieve comparable characteristics as quickly as SONOS. That is to say, SONOS could provide the required fast-read access times (35 nanoseconds) within the BSTS and SSTS timeframe and be manufacturable by VLSI techniques. (Time: 2 years)
- Develop a Technology Feasibility Demonstrator for Advanced Signal and Data Processing. This is to facilitate the insertion of algorithms, architecture, software, and hardware into an integrational test bed for comparison with competing technologies and to assess performance of various alternatives. The key issue is whether to merge many small independent academic research projects into a central integrated facility to demonstrate the most advanced computing technology. Much of what has already been developed can solve many of the current BSTS and SSTS signal processing problems.

6.7.2 Small Business Innovative Research

This section describes SBIR projects and their accomplishments and future plans.

Projects

Pursuant to Public Law 97-219, the SBIR project is providing seed capital to technology innovators in small American businesses. IST administers the competition for Phase 1 awards nominally of $50,000 for a feasibility study, followed by further competition to expand the project to $500,000 (Phase 2) over 2 years.

SBIR rewards innovations by small firms all over America where seed capital is needed to mature the technologies enough to attract users and venture capitalists. SDI spreads 1.25 percent of its extramural R&D among hundreds of firms developing high technology innovations that help SDI and also hold promise of commercialization.

Competition is keen; only one-fifth of the candidates obtain $50,000 first phase awards, and only a fourth of those receive $500,000 second phase awards. However, the number selected in Phase 1 is twice the DOD average because SDI believes in giving more ideas an early chance to be proven meritorous. The 1.25 percent allotment will continue in accordance with Public Law 97-219, although new legislation is under consideration to increase that allocation.

The first SDI Phase 2 of SBIR will be finished in mid 1989. Further development of these concepts by SDI, DOD, and other potential users will follow. Contract technical managers in the government (or national laboratory), where the technology is likely to be used, are encouraging and assisting firms in finding clients for the technology within the Defense Department. The SDI Program managers most interested in the technology will receive the technical reports.

SBIR supports all SDI technologies by offering options for development of innovative concepts for components. SDI technical managers review proposals for both phases of the competition.

Accomplishments

Current Phase 1 and Phase 2 contracts cover 15 technical topics which include all the SDI technologies. The present program allows about 120 simultaneous Phase 2 contracts and 150 Phase 1 contracts. Phase 2 winners are pursuing advancements in: free electron lasers, neutron detectors, electromagnetic guns, cryocoolers, focal plane arrays, range measuring lasers, spatial light modulators for optical computing, object discrimination, pointing and tracking of space platforms, batteries, magnetohydrodynamic power, high current switches, diamond films, high temperature composite materials, new electronics fabrication, radiation-hard electronics, software for battle management, electric propulsion thrusters, cubane-based high energy propellants, heat pipes, and magnetic bearings.

Future Plans

The SBIR program will continue to be funded at the level mandated by Public Law 97-219. The expectation is for 130 Phase 1 awards and 120 Phase 2 awards. The completion of the first Phase 2 awards will allow an evaluation to be initiated to determine how well SBIR meets the objectives of the Public Law.

Section 6.8

Technology Applications

6.8 Technology Applications

This section describes the transfer of technology generated by SDI efforts and its application to a number of civilian scientific endeavors. Appendix E contains a detailed summary of these efforts.

6.8.1 Projects

SDI provides an opportunity to transfer technology to other defense and public and private sector organizations, as it is redefining the state of the art through its research and development in a vast array of new and unexplored areas. SDIO maintains broad-based research requirements to expand and accelerate the identification, design, and development of relevant technologies. As such, SDI research is examining a number of concepts that make use of a wide range of technologies. The products and processes generated from SDI research also serve as a source of technological innovations for other defense and private and public sector research and development activity. SDI research has already, for instance, produced spinoffs in medicine, electronics, optics, computer technology, communications, the transmission of energy, and materials and industrial processes.

The technology-push approach features the SDI Technology Applications Information System (TAIS), a computer data base established to provide rapid review of information to qualified corporations, citizens, and federal agencies. The TAIS provides technology abstracts that describe SDI research, and other information on specific set-aside research opportunities for small businesses; innovative research requirements for SDI; manufacturing technologies needed to support SDI; points of contact at federal, state, and local technology transfer offices and private sector foundations; and other technology transfer data bases. Once the user identifies the technology of interest, the SDIO will connect the user with the SDI researcher or developer and track that contact to determine the need for additional assistance.

6.8.2 Accomplishments

The SDIO technology applications program has provided technology transfer information and initiated a dialogue with developers in a large number of scientific disciplines. A partial list of work in this area undertaken during the past fiscal year is shown in Figure 6.8-1.

Because a separate Technology Application appendix has been created in response to the Congressional directives which resulted in the formation of the SDIO Office of Technology Applications, more detailed descriptions of work in this direction is deferred to Appendix E.

At the direction of the Congress, the Medical Free Electron Laser (MFEL) program was initiated within SDIO to establish FEL research facilities and conduct biomedical and materials research. (See Figure 6.8-2.)

Figure 6.8-1
Technology Applications Efforts

Medicine	**Electronics**
Biomedical Materials for Rehabilitation High-Speed Computer Applications in Medicine Ophthalmology and Eye Surgery Applications Sensors for Medical Diagnosis Neutral Particle Beam Diagnosis/Therapy	Detection of Explosives Nondestructive Inspection New Power Sources for Medical Devices Supercomputer Applications
Space Technology	**Agriculture**
SDIO-NASA Cooperative Research Space Transportation	Harmful Insect Detection Food Preservation
Energy	**Industrial and Materials Products**
Superconducting Magnetic Energy Storage Oil Well Exploration	Superconducting Materials Diamond Crystal
Devices and Technologies for Industry	**Environment**
High-Power Ballistics Advanced Thermoelectric Converters Cryogenic Alternators Advanced Cooling Devices	Ozone Layer Protection Acid Rain Reduction Nuclear Waste Disposal Automotive Pollution Control

The MFEL program is national in scope and draws upon the resources and expertise of 20 universities, 2 national laboratories, 2 commercial laboratories, and a teaching hospital to explore the following areas:

- Preclinical medical research, such as surgical applications, therapy, and the diagnosis of disease
- Biophysics research into medical laser applications at the cellular level
- Materials science, including the development of materials for use in laser therapy for cancer treatment.

Recent developments in high temperature superconductors (HTS) have created opportunities for SDIO HTS technology to be spun off to enhance national research and development capabilities. The application of superconductors to wind tunnel test facilities, shown in Figure 6.8-3, will lead to advances in aeronautics for utilization in commercial and military aircraft.

Figure 6.8-2
MFEL Program

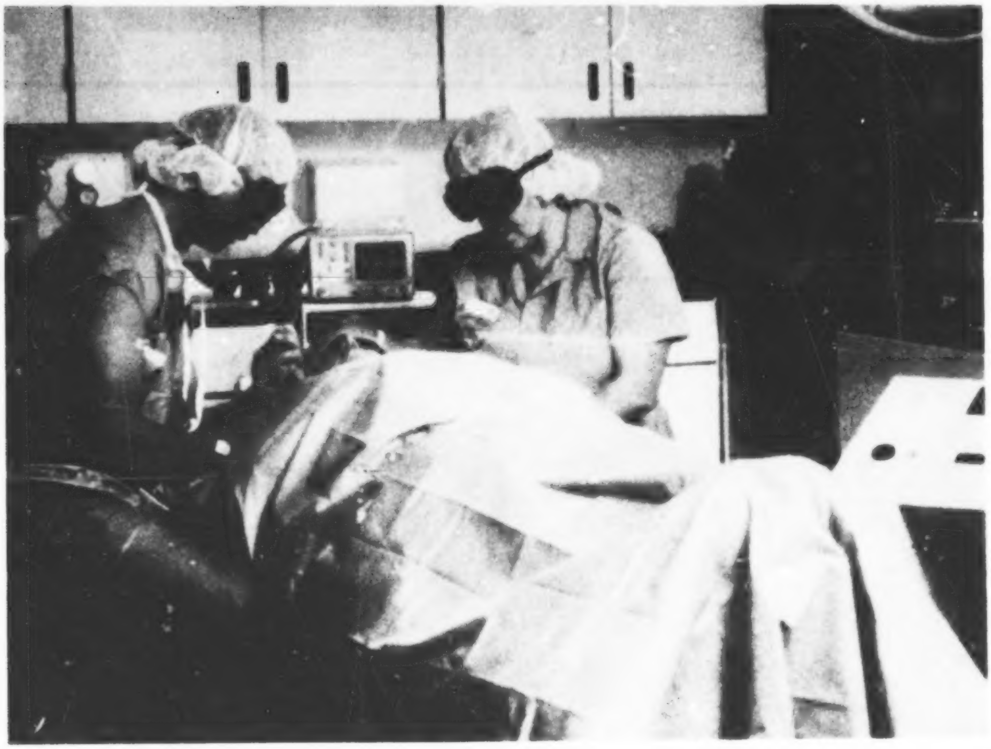


Figure 6.8-3
Wind Tunnel Tests

Super magnets for
large tunnels

Section 6.9

Special Projects Program

6.9 Special Projects Program

This section describes the four major test project areas which make up the Special Projects program.

6.9.1 Project Overview

The objective of the Special Projects program is to identify and bring together near-term concepts that have unique aspects which may provide high-leverage results to advanced systems and technologies. Working closely with all offices of the SDIO, the Special Projects office examines emerging new concepts for their required ground or flight tests needs. Based on common or similar experimental test requirements (not similar system interfaces), these concepts are fused together into integrated experiments. This approach provides a test bed for multiple experiments which, when viewed independently, may not warrant the investment of a dedicated flight test. When combined, however, the aggregate experiment provides considerable multidisciplined results and resolves a substantial number of near-term technology of implementation issues for advanced or special systems applications.

6.9.2 Technical Objectives

The Special Projects program has currently identified four major test project areas. The first two areas are related in that they are flight test programs that are jointly conducted in space. The Delta Star spacecraft and Black Brant sounding rockets in support of Delta Star (Black Star) will be fully executed and completed in FY 1989. The data from these experiments will be incorporated into the Phase I and Phase II data bases and will be used to advance specific architectures and technologies.

Delta Star Satellite

The Delta Star spacecraft is a moderate-life (6 months) orbital platform designed to collect high spatial and temporal resolution imaging data in the technical areas shown in Figure 6.9-1.

The spacecraft configuration (Figure 6.9-2) shows heritage from the Delta 180 (Vector Sum) and Delta 181 (Thrusted Vector) programs. The sensor module contains seven imaging sensors and a low-power laser radar to acquire and observe ground-generated experiments and atmospheric and near-space phenomena.

Black Star Sounding Rockets

A minimum of six sounding rockets are planned for launch, each specifically tailored to be observed by the Delta Star spacecraft. Delta Star reliability and low fuel consumption allow continued operation beyond its expected life. Additional launches may be generated. Figure 6.9-3 provides a summary of the Black Star launches.

Figure 6.9-1
Delta Star Objectives

Objectives
Collect multispectral data of plumes
Collect multispectral background data including earth, earth limb, and Aurora
Collect data to analyze environmental effects on space materials
Collect multispectral data on chemical releases
Investigation of Laser Illumination Detection System (LIDS)

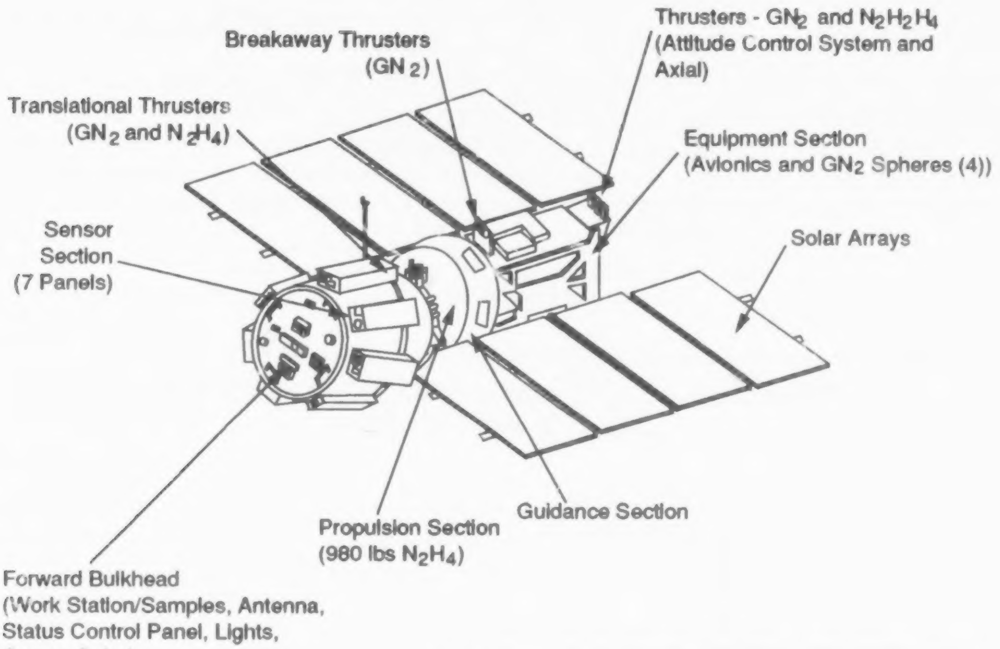
Hybrid Kill Mechanisms

Planned research on hybrid kill mechanisms seeks to develop a unique combination of both kinetic and directed energy kill mechanisms in a single weapon concept. Work on this program will determine the potential lethality of the system in momentum transfer, kinetic transfer, and electromagnetic pulse (EMP) generation. Efforts in FY 1989 are focused on power scaling and accuracy of placing the kill mechanism. Based on current testing, FY 1990 efforts may include a ballistic flight experiment to test a preprototype system in the actual space environment. Such a test would allow testing across greater distances than existing vacuum chambers allow. If both the power and accuracy can be shown to be a tenfold increase over the FY 1989 objective levels, a flight test may be justified in FY 1990.

Advanced Implementation Technologies

Advanced Implementation Technologies involve the integration of near-term but high-risk advances in guidance, astronavigation, and pointing into a miniaturized and lightweight system. Such a system would have significant benefits in performance and weight/cost savings over existing concepts on virtually all space platforms. Testing in

Figure 6.9-2
Delta Star Spacecraft


Thrusters - GN$_2$ and N$_2$H$_2$H$_4$ (Attitude Control System and Axial)
Breakaway Thrusters (GN$_2$)
Translational Thrusters (GN$_2$ and N$_2$H$_4$)
Equipment Section (Avionics and GN$_2$ Spheres (4))
Solar Arrays
Sensor Section (7 Panels)
Guidance Section
Propulsion Section (980 lbs N$_2$H$_4$)
Forward Bulkhead (Work Station/Samples, Antenna, Status Control Panel, Lights, Corner Cube)

Features
• Supports Mission Life ≥ 180 Days • Maximizes Use of Available Hardware • Accommodates All Required Equipment and Sensors to Achieve Mission Objectives

FY 1990 is planned to include ballistic flight tests outside the atmosphere to determine system operating characteristics in a realistic environment.

Funding Impacts

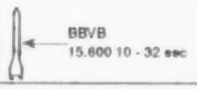
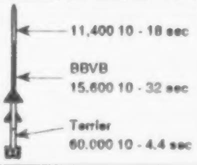
Basic special projects goals were accommodated in FY 1989 with the funding of the Delta Star spacecraft and six Black Star launches. Upon completion of these experiments, the exploitation of the resulting data will require modest but stable funding in FY 1990. Budget limitations in FY 1989 allow for the completion of flight test efforts late in the fiscal year, but do not provide for the full utilization (data reduction, computer code enhancement) of this information. Exploitation of the flight data can only be accomplished in FY 1990 if overall funds reflect real growth in the SDIO budget.

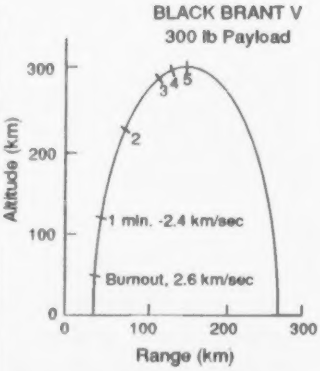
Figure 6.9-3
Black Star Launches

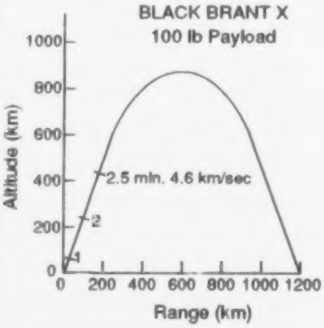
Program Name	Program Description
Black Star 1 Black Star 2	Low altitude fuel release experiments
Black Star 3 Black Star 4	High altitude fuel release experiments
Black Star 5 Black Star 6	Energetic interaction experiments

Note: Most likely sounding rocket candidates are Black Brant VB and Black Brant X.

Typical Performance Parameters and Flight Profile of Black Brant VB and Black Brant X

	BLACK BRANT VB	BLACK BRANT X
		 11,400 10 - 18 sec BBVB 15.600 10 - 32 sec Terrier 60.000 10 - 4.4 sec
Usable Payload	17 to 19 lbs	17 to 19 lbs
Number of Stages	1	3
Typical Performance at 200	650 lbs	>1,200 lbs
Max. alt. for 300-lb Payload	310 km	800 to 1,000 km
Burnout conditions for a 300-lb Payload - Time - Altitude - Velocity - Max g	 32 sec 27 km 1,000 FPS (2.5 km/sec) 13.5 g	 100 sec 123 km 12,500 FPS (3.8 km/sec) 22 g
Velocity at (for a 300-lb Payload) - 100 km - 250 km	 2.2 km/sec (at 60 sec) <1.9 km/sec (at 170 sec)	 Still powered 3.5 km/sec (at 125 sec) 4.4 km/sec for a 100-lb pt
Recurring Cost	125 k	225 k
Recurring Costs	50 to 100	50 to 100


BLACK BRANT V
300 lb Payload


BLACK BRANT X
100 lb Payload

The hybrid kill mechanism and advanced implementation technology programs, based on completion of FY 1989 goals, will require tenfold increases in FY 1990 to allow flight test. Although relatively small efforts (less than $3 million each) for hardware experiments currently exist, these programs have the potential for great leverage for both SDIO and other space-related programs. Adequate funding of advanced concept systems will also require real growth funding in FY 1990.

6.9.3 Accomplishments

The Special Projects activities have brought to completion two major programs—the Delta Star spacecraft and the Black Star launches. Preliminary ground experiments will have been completed on the advanced concepts involved in hybrid kill mechanisms and advanced implementation technologies. The maturing of these efforts in realistic space flight experiments remains to validate these items for Phase II application.

6.9.4 Future Plans

The Special Projects will continue to exploit future opportunities to perform integrated experiments where there are common or similar experimental test requirements.

Chapter 7

SDI Program Management

The SDIO management team discusses program strategy.

Chapter 7

SDI Program Management

When the SDI Program formally entered the defense acquisition process in June 1987, it was required to meet all of the major DOD acquisition milestones, including continuous extensive review by the Defense Acquisition Executive (DAE) and his review mechanism, the Defense Acquisition Board (DAB). To meet attendant technical and management challenges, SDIO has taken steps to improve the management structure and develop new management tools to guide and direct the Program. These management tools are designed particularly to promote coordination and cooperation within the SDIO and with external organizations. The overall emphasis is to do the best job possible with the resources available and to hold individuals accountable in the pursuit of the Program goals.

7.1 Management Approach

The current charter of the SDIO (as specified in DODD 5141.5, Strategic Defense Initiative Organization, dated 4 June 1987) states:

> SDIO shall manage and direct the conduct of a vigorous research program, including advanced technologies, that will provide the basis for an informed decision regarding the feasibility of eliminating the threat posed by nuclear ballistic missiles of all ranges, and of increasing the contribution of defensive systems to U.S. and allied security. The program shall protect options for near-term deployment of limited ballistic missile defenses. The program shall be carried out in full consultation and, where appropriate, with participation of our allies. The program shall be conducted in compliance with all existing treaty obligations and will emphasize non-nuclear technologies.

Key to success of the Program is strong central directive authority vested in the Director, SDIO. The Director has been given the authority and responsibility, and is accountable to the Secretary of Defense, for the successful execution of a robust research program balanced with the system development activities. The Director has also been designated the SDI Acquisition Executive (SDIAE). While the Program is centrally managed by SDIO, execution of the individual element technology and development efforts are delegated to and executed by the Services and other participating agencies. Therefore, effective communications and teamwork among all Program participants—SDIO, the Services, the JCS, the user, and other agencies—are essential. The Director's centralized oversight of all SDI work and resources, and his direct interaction with the Acquisition Executive of each Service, ensure that the Program is properly focused and successfully integrated at all levels.

To ensure that SDIO establishes and maintains the capability to manage effectively the full scope of the Program, the following set of management guidelines and activities has been implemented:

- SDI Program authority and the programmatic decision process will flow from the Defense Acquisition Executive (OSD, Under Secretary of Defense for Acquisition) to the SDIAE to the Service Acquisition Executives (SAEs).
- All Program activity is under the broad direction and control of the Director, who will direct the use, as appropriate, of existing management and technical expertise of the SDIO, the Services, and other participating agencies.
- The acquisition strategy for the strategic defense system (SDS) will follow a phased development approach (Phase I has entered the Dem/Val stage of the defense acquisition process).
- Internal SDIO offices have been established to manage effectively the acquisition, the definition of follow-on phases, and the continuing research necessary for future planning of Phase I. As part of the SDS Phase I effort, an SDS Program Executive Officer (PEO) (the Deputy for Systems) and an SDS Phase I Program Manager (PM) have been designated.
- External to SDIO, Service and agency responsibilities have been identified in coordination with the appropriate DOD officials. These responsibilities will continue to evolve as the Program matures and progresses through the acquisition process. The Services have designated PEOs and PMs for the individual element programs they are assigned to execute for SDIO. The Service element PMs plan and execute their designated element program in consonance with SDIO-approved plans and guidance from the SDS Phase I PM.
- Technical and program direction and funding cover both systems development and continuing research necessary to carry out Service-managed element programs and other agencies' SDI activities to the element PMs in accordance with agreements between the Director and the SAEs and appropriate agency directors.
- A systems engineering and integration (SE&I) contractor has been selected to support the SDS Phase I PM and the Services in accomplishing the Phase I activities.

7.2 Organizational Structure

The SDI program management structure provides for balanced emphasis on system development and technology research, effective SDIO control and coordination of Service and other agency-managed programs, and accountability of all PMs for project execution. Also, it provides the Director the means to direct and integrate all SDI Program activities.

The SDIO completed an internal realignment on 1 October 1988 (see Figure 7-1). Principal factors that led to the realignment were the Director's desire to create a better management structure for Phase I, plus a general desire to support internal common needs better and provide SDIO the focus it needs to successfully develop the strategic defense system. In explaining the organizational realignment, the Director stated:

> ...a major objective of the realignment is to concentrate the concept definition, system trade-offs, and integration and management of the six Phase I elements into the Phase I Program Office of the Systems Deputate. Threat projections, architectural effectiveness, and launch concepts will be centralized in the new Architectures and Analysis Directorate, also in the Systems Deputate. The technology base that supports both Phase I and follow-on system concepts will now be concentrated according to technology discipline in the Technology Deputate. In addition, resource management functions will be combined to obtain maximum utilization of limited manpower spaces and to reduce the span of control over staff offices.

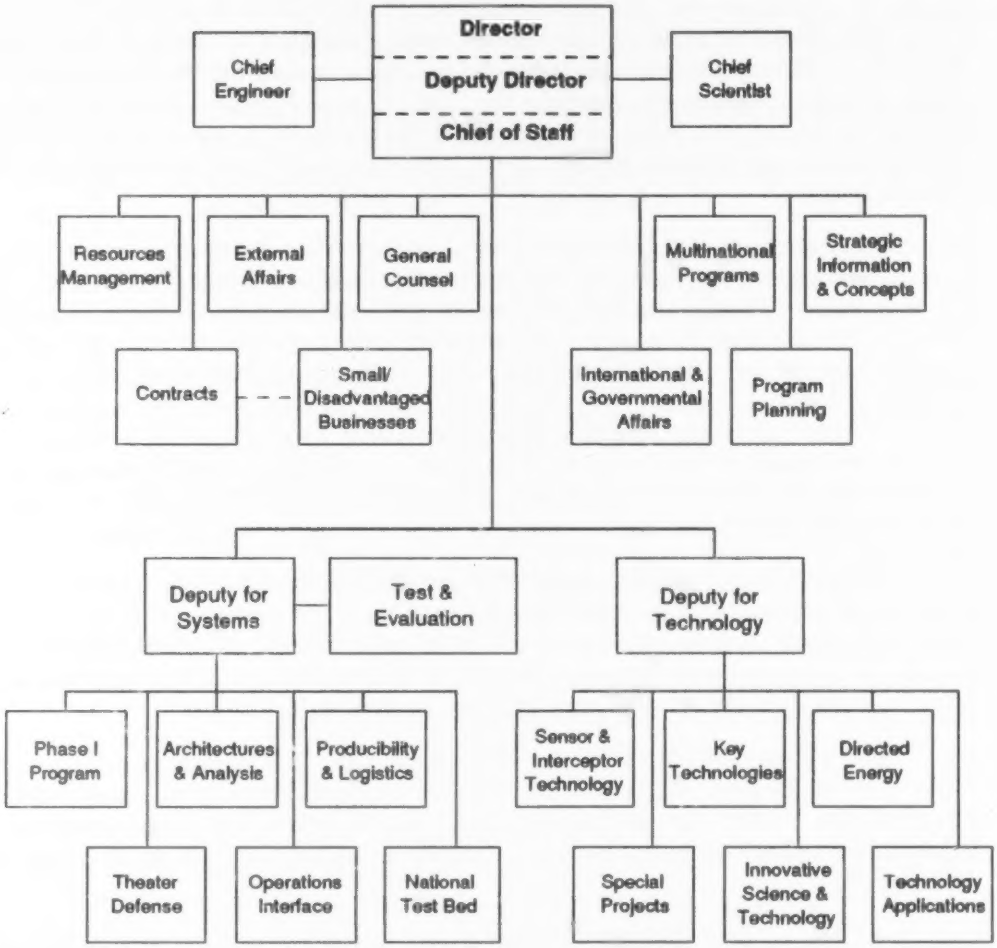
The realignment moved some of SDIO's technical functions and programs away from the previous matrix structure and into a more streamlined organization. This move will enable increased accountability for program performance within SDIO and among its many executing agents. Also, the realigned SDIO management structure effectively parallels the Services' own program management.

The realignment did not suggest a change to either the immediate or long-term objectives of SDI nor did it change total budget submissions or total staffing requirements. What this reorganization did was to streamline management of a balanced technology evolution and greatly improve responsiveness to the Secretary of Defense.

A Chief of Staff position has been added to better coordinate traditional staff functions with line management in the System and Technology Deputates. A Chief Engineer position also has been added to provide top-level oversight of, and visibility to, the variety of engineering tasks and analyses to be accomplished.

An important feature of the SDI management network is the special role that the Command Center (CC) element and System Operation and Integration Functions (SOIF) play in the overall system development program. Because CC/SOIF is expected to link all the SDS elements into a cohesive ballistic missile defense, SDIO intends to maintain direct control over related technology research, system development, and system integration activities. However, within CC/SOIF specific projects are delegated to the Services and other key agencies to accomplish program objectives. The management network for accomplishing future CC/SOIF projects is still evolving.

Figure 7-1
Strategic Defense Initiative Organization


Director
Deputy Director
Chief of Staff
Chief Engineer
Chief Scientist
Resources Management
External Affairs
General Counsel
Multinational Programs
Strategic Information & Concepts
Contracts
Small/ Disadvantaged Businesses
International & Governmental Affairs
Program Planning
Deputy for Systems
Test & Evaluation
Deputy for Technology
Phase I Program
Architectures & Analysis
Producibility & Logistics
Sensor & Interceptor Technology
Key Technologies
Directed Energy
Theater Defense
Operations Interface
National Test Bed
Special Projects
Innovative Science & Technology
Technology Applications

7.3 Programmatic and Financial Management

This section discusses work package directives (WPDs), information resources management, the Financial Management Board (FMB), and the Defense Acquisition Review Team (DART).

Work Package Directives

To achieve centralized planning, programming, budgeting, and execution of the SDI Program, WPDs are used to provide formal guidance and directions to the Services and other agencies. WPDs support program planning, budget submissions, and monitoring of program execution by providing information on approved research efforts. Development of WPDs is a coordinated effort between the SDIO WPD manager and the Service or agency program manager. Once a WPD has been defined, staffed, and determined to be within SDI Program resource constraints, it is signed by a senior executing agent official and the Director, SDIO. The approved WPD becomes an agreement for program execution. The WPDs have been and continue to be evaluated. They are evaluated when the respective programs are audited by either the General Accounting Office (GAO), DOD, the Inspector General (IG), the Military Service audit teams (e.g., Army Audit Agency), or the Military Service IG and internal review teams. In addition, SDIO holds semiannual budget execution reviews where selected WPDs are reviewed to evaluate execution.

Information Resources Management

The SDIO is establishing a full information resources management (IRM) program. Work associated with this program include the development of a 5-year automated information systems plan, the development of a management information system, the establishment of SDI-wide IRM policy and procedures, and the review and coordination of SDI-wide efforts associated with the development of computer and telecommunication systems. The results of this activity will significantly enhance the ability of the SDIO and its executing agents to effectively manage the many projects associated with the SDI Program.

Financial Management Board

The FMB reviews proposed program and budget guidance, SDI programming and budgeting actions, and fiscal performance during the year, and makes recommendations to the Director on issues related to these activities. The FMB is chaired by the Deputy Director, SDIO. Primary members include the Deputies for Technology and Systems; the Director, Resource Management; and the Director, Program Planning. Other SDIO offices may provide representatives to act in an advisory capacity. The Services and other agencies may send representatives to FMB meetings at the request of the chairman.

Defense Acquisition Review Team

The DART was established in September 1987 to guide and oversee planning and preparation for the first annual Defense Acquisition Board (DAB) review. On 29 February 1988, the Director established the DART as a permanent SDIO activity under the direction of the Deputy for Programs and Systems (now Deputy for Systems). At the same time, the DART's role was expanded to provide a central mechanism to integrate all SDIO Directorates in accomplishing short-notice tasks, special projects, and information dissemination related to strategic defense system efforts. The DART continues to guide and oversee planning and preparation for the annual DAB reviews, which require the participation and cooperation of the OJCS, DOD staff, the Services, and the Space Command.

7.4 Internal Management Controls

A directive system has been established to provide for effective communication among all SDI Program participants funded by SDIO. Management directives on SDI standards, guidance, and implementing procedures have been created for a wide range of topics. SDIO management directives are closely tied to and are consistent with work identified in the WPDs approved by the Director.

Using the tools described above, the SDIO has this past year significantly strengthened its internal management control (IMC) program. The focus has been in three key areas: senior management involvement and direction, the performance of internal control evaluations, and the tracking of all corrective actions identified through the internal control evaluation process. During FY 1988, the SDIO successfully completed all of the steps of the IMC process as outlined in DOD Directive 5010.38. Some of the FY 1988 initiatives included the following:

- An increase in the number of Management and Oversight Division personnel from two to four (this staff is dedicated to developing internal control processes, ensuring organizational accountability, and coordinating immediate audit resolution and audit follow-up).
- Development of an SDIO Internal Management Control Review (IMCR) Manual for conducting necessary reviews.
- Completion of IMCR evaluations for scheduled internal control reviews, including agency briefings to all SDIO Directors.
- Development of many new agency policy directives outlining streamlined procedures and internal controls to improve management effectiveness. New directives include the small business innovative research program, contracted advisory and assistance services, employment of experts and consultants by personnel appointment, committee management program, and contracting requirement process.
- Completion of management oversight visits of the IMC program implementation by the SDIO executing agents (i.e., Army, Navy, Air Force, DARPA, DNA, and DOE).
- Development of an audit follow-up tracking system to schedule corrective milestones for agency deficiencies discovered through any review process (i.e., GAO/IG audits and surveys; DOD Reorganization Act surveys; risk assessments or internal management control reviews; Congressional hearings; and agency management reviews).
- Development of the FY 1989 Management Control Plan for scheduling management reviews over a 5-year period.

As a result of these efforts, the DOD Inspector General conducted an evaluation of the SDI Program in August 1988 and concluded that the framework is in place to ensure compliance with the Federal Manager's Financial Integrity Act.

best copy available

Chapter 8

SDI Program Funding

BUDGET
OF THE
UNITED STATES
GOVERNMENT
FISCAL YEAR
1990

Chapter 8

SDI Program Funding

This chapter addresses SDI Program funding and related contracts. It depicts large budget reductions in the FY 1985, FY 1986, FY 1987, FY 1988, and FY 1989 requested levels. These reductions have cut back the number of promising technologies that could have been pursued in parallel, thereby increasing the difficulty of realizing solutions to specific technical issues.

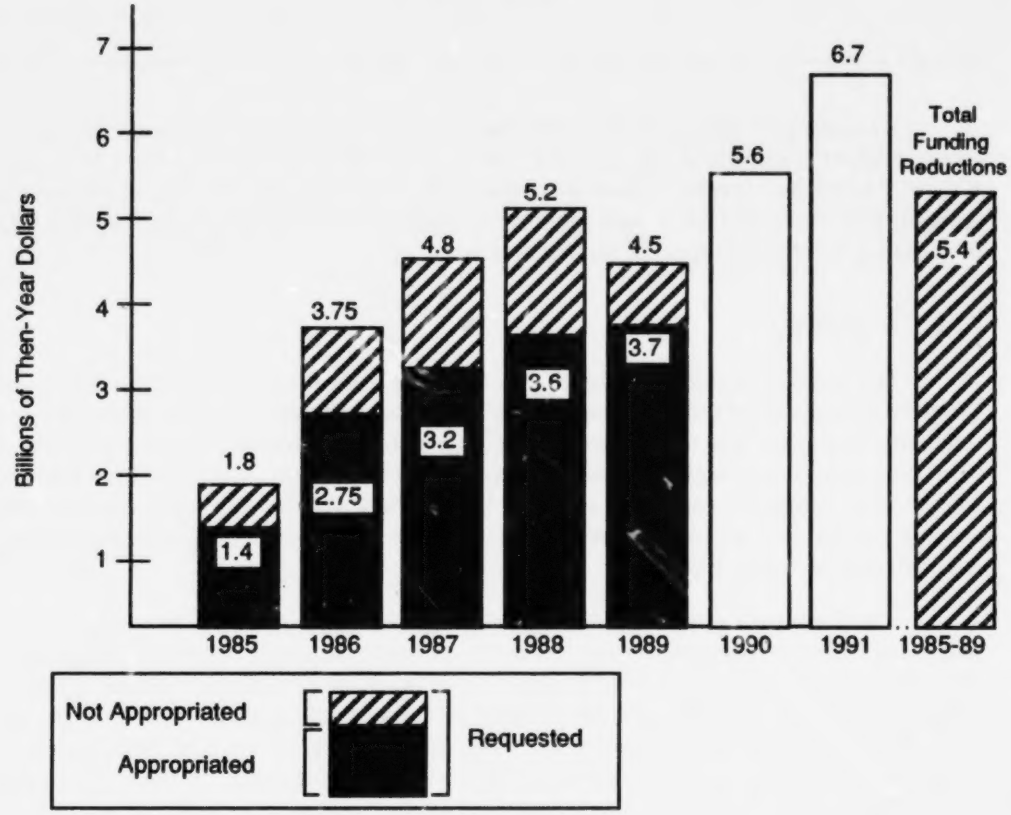
8.1 Funding

While the Congress has increased SDI Program funding each year since the Program's inception, the difference between what the Administration has requested and what the Congress has appropriated is so great (see Figure 8-1) that it has had a substantial and increasingly detrimental impact on the Program. Congressional funding for the SDI Program was again reduced below the President's request in FY 1989 despite the DOD's reexamination of last year's program and its submission of the smallest request since FY 1986.

The Defense Department is faced with the dilemma of either delaying the time when a decision on whether to deploy defenses could be made or totally eliminating some technology efforts, thereby reducing the number of defense options that can support a decision. Specifically, the progress of some portions of the SDI Program has been slowed approximately 1 to 2 years. The SDIO has, in essence, slowed its rate of progress on some technologies needed to hedge against potential Soviet countermeasures. In light of the potential Soviet threat, the SDIO is extremely concerned about this slowdown. Despite reductions in the Administration's requests, the SDIO is still pursuing a program in which both technology base and technology validation efforts receive a balanced emphasis. The SDIO will not be able to maintain this essential balance if the trend of relatively large cuts from SDI budget requests continues.

While the SDIO has focused on the technologies that could be used to sustain performance growth to increasing levels of defense, work on some technology candidates has been either reduced or eliminated. The SDIO has retained its goal of pursuing innovation, but it is forced to do so at a smaller rate of investment. Changes, some of which may be irreversible, have lengthened the time within which a decision on whether to develop and deploy effective defenses can be made but have limited the technical options that will be available during that time. In addition, the elimination of alternatives, including those of higher risk but higher payoff, has increased the possibility of SDIO's goals falling short.

Figure 8-1
SDI Program Budget Requests vs. Appropriations (By Fiscal Year)



The SDIO is reducing funds for some of its programs. For example, cuts to the SSTS program have forced the systems program office to renegotiate awarded contracts, adding cost, increasing risks, and delaying critical technology program demonstrations. The same type of decision was made in the kinetic energy weapons technology program, where validation work on electromagnetic launchers was cut back to support the technology validation of the more mature chemically propelled kinetic-kill vehicles.

The SDIO remains resolute in pursuing vigorously a focused and decision-oriented program with well-defined objectives, despite Congressional decisions not to fund the SDI Program at the requested levels. This goal is threatened, however, by proposals to limit real growth. If SDI funding continues to be limited, as in the past, the United States will not be able to take full advantage of its greatest leverage—the innovation possible in a free society—and it cannot expect to do more than react to

Soviet initiatives in strategic defense. If U.S. tenacity to develop options for a thoroughly reliable defense is to be rewarded, funding must be sufficient to allow the SDIO to pursue effectively options for strategic defense of the United States and its allies.

The Defense Department has submitted budget requests of $5.6 billion for FY 1990 and $6.7 billion for FY 1991 just to continue the Program. Details of the FY 1990-91 budget submissions are presented in Tables 8-1 and 8-2. These tables portray the budget by the established program elements and the major activities described in Chapters 5 and 6.

8.2 SDI Contract Execution

As discussed in Chapter 7, all SDI Program activity is under the broad direction and control of the Director, using, as appropriate, the existing management and the technical expertise of the SDIO, the Services, and other agencies. This includes the contracting expertise and resources of those organizations. Figure 8-2 shows the funding distribution by executing agent for FY 1988.

SDIO has established its own in-house contracting capability to provide a central execution capability for several types of contracting actions. First, it provides contracting support for systems engineering such as the SDI Systems Engineering and Integration (SE&I) effort. The second type of contracts issued at SDIO is for special experiments and demonstrations that are managed by the SDIO technical offices instead of SDIO agents. Contracting support is also provided for in the negotiation of Memorandums of Understanding with foreign governments for future SDI projects. The final category of in-house contracting support provided is for those actions required to support the day-to-day operations of SDIO.

Since the establishment of the SDIO Contracts Directorate in FY 1986, the level of activity has grown from $21 million in obligations to $234 million in FY 1988. Examples of some of the contracts awarded in FY 1988 are the SE&I contract ($235 million) discussed in Chapter 5, and the Delta Star and Zenith Star experiment contracts as described in Chapter 6.

To provide proper oversight of the executing agents, SDIO has implemented several management control tools, such as the SDI Contract Data Base and the SDI Contracts Steering Group.

The SDI Contract Data Base currently contains 16,000 records of contracting actions executed by SDIO and its agents. It includes such information as contractor names, contract/modification numbers, dollars obligated, extent of competition, and type of business. To further enhance our ability to capture SDI contract data, SDIO implemented in 1988 a unique SDI "system code" on the DD 350 form that reports

Table 8-1
Program Funding for FY 1988-91
By Program Element and Project (in Millions of Dollars)

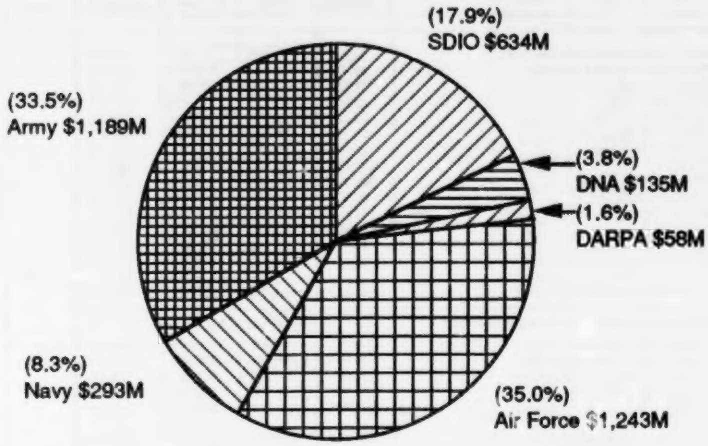
PE #	PROJECT #	TITLE	FY88 $ Actual	FY89 $ APPN	FY90 $ Request	FY91 $ Request
0603220C		**Surveillance, Acquisition, Tracking, and Kill Assessment Projects**				
	01	Radar Discrimination and Data Coll	16.267	21.175	38.995	28.952
	02	Optical Discrimination and Data	99.078	110.894	123.822	163.747
	03	Microwave Radar Tech	17.208	14.523	28.956	28.963
	04	Laser Radar Tech	79.850	80.771	96.052	101.659
	05	Passive Sensor Tech	55.841	71.209	95.864	105.842
	06	Signal Processing Tech	66.122	81.943	100.846	108.827
	07	Interactive Disc Tech	23.141	13.980	37.941	41.932
	08	Boost Dem/Val	173.999	235.000	67.511	0.000
	09	Midcourse Dem/Val	37.746	107.959	163.754	314.816
	10	Midcourse Experiment	39.701	93.891	42.080	28.953
	11	Terminal Dem/Val	36.882	72.963	144.475	180.343
	12	SATKA Support	117.215	122.880	217.846	214.114
	81	IS&T	58.374	43.288	98.605	114.696
	82	Delta Star	7.500	0.000	0.000	0.000
	83	Support Programs	43.510	31.881	32.962	35.016
		TOTAL SATKA	934.508	1100.738	1281.023	1438.000
0603221C		**Directed Energy Projects**				
	20	FEL	172.055	202.322	275.082	302.010
	21	ATP	252.348	183.881	254.617	244.610
	22	CL	100.080	100.139	348.498	511.190
	23	NPB	109.018	98.998	114.829	114.798
	24	MIRACL/T	27.500	4.000	0.000	0.000
	25	CDTI/Emerging Tech	167.142	96.153	64.729	62.492
	81	IS&T	19.315	15.000	34.130	40.888
	82	Delta Star	65.218	72.962	0.000	0.000
	83	Support Programs	21.610	48.894	27.089	17.274
		TOTAL DEW	934.266	819.759	1118.982	1322.877
0603222C		**Kinetic Energy Projects**				
	30	Space Systems	165.000	132.000	349.298	360.412
	31	Exo KKV Systems	116.000	202.255	244.225	293.919
	32	Endo KKV Systems	106.250	145.875	218.984	191.468
	33	Advanced Tech Weapons	117.582	89.105	217.673	311.807
	34	Test and Evaluation	133.105	68.015	107.137	145.985
	35	Technology Support	5.658	9.405	9.898	9.546
	42	Theater Defense	67.958	75.767	139.290	149.657
	81	IS&T	23.365	21.702	41.277	49.190
	82	Delta Star	6.147	0.000	0.000	0.000
	83	Support Programs	22.102	28.967	22.467	22.974
		TOTAL KEW	773.167	773.111	1349.514	1534.857
0603223C		**Systems Analysis and Battle Management Projects**				
	40	SDS Engineering and Support	72.590	82.095	131.407	201.071
	42	Theater Defense	50.500	30.805	48.922	46.720
	43	CC/SOIF Technology	64.306	58.572	88.398	107.817
	44	CC/SOIF Experimental Systems	91.073	74.179	143.778	203.071
	45	National Test Bed	77.719	100.179	115.827	121.802
	46	SDS Phase I Engineering	45.201	69.470	125.210	155.831
	47	Test & Evaluation	5.861	8.477	9.885	14.977
	81	IS&T	12.885	16.350	25.832	30.802
	83	Support Programs	22.062	53.289	70.588	70.871
	56	Technology Applications	18.466	20.277	22.967	22.968
		TOTAL SA/BM	461.459	508.476	780.854	975.627
0603224C		**Survivability, Lethality, and Key Technology Projects**				
	50	Systems Survivability	91.305	102.891	169.460	218.114
	51	Lethality and Target Hardening	68.641	62.218	124.434	152.128
	52	Power and Power Conditioning	97.204	99.509	205.296	236.979
	53	Space Transportation and Support	79.558	58.000	124.809	154.750
	54	Materials and Structures	24.890	30.731	68.428	86.081
	55	Countermeasures	21.245	22.270	34.994	42.366
	81	IS&T	23.600	18.376	40.905	48.610
	83	Support Programs	23.131	15.248	8.472	8.578
		TOTAL SLKT	429.574	408.343	776.787	947.576
0604220C	60	BSTS FSD	0.000	0.000	262.000	427.000
0605898C	83	Management Headquarters	20.028	21.000	26.394	27.456
		TOTAL RDT&E RESOURCES	3553.000	3627.424	5590.504	6671.093
		Military Construction	59.195	83.000	12.942	40.179
		TOTAL DEPARTMENT OF DEFENSE	3612.195	3710.424	5603.446	6711.272
		DOE SDI Program	353.800	336.000	311.000	276.000
		TOTAL SDI PROGRAM DOD/DOE	3965.995	4046.424	5914.446	6987.272
		NASA ALS	70.000	96.500	0.000	0.000

Table 8-2
Program Funding for FY 1988-91 *
By Major Activity and Project (in Millions of Dollars)

TITLE	FY88 $ Actual	FY89 $ APPN	FY90 $ Request	FY91 $ Request
Sensors and CC/SOIF				
Radar Discrimination and Data Coll	18.267	21.175	28.965	28.952
Optical Discrimination and Data	99.078	110.594	123.822	163.747
Microwave Radar Tech	17.285	14.323	28.956	28.953
Laser Radar Tech	79.850	80.771	96.852	101.839
Passive Sensor Tech	55.841	71.299	95.864	105.842
Signal Processing Tech	66.122	81.943	100.848	106.827
Interactive Disc Tech	23.141	13.980	37.941	41.982
BSTS Dev	173.993	235.000	329.511	427.000
Midcourse Sensor Dev	37.746	107.956	163.754	314.816
Terminal Sensor Dev	36.882	72.368	144.475	150.343
SATKA Support	117.215	122.590	217.548	214.114
Delta Star	78.865	72.962	0.000	0.000
CC/SOIF Technology	64.306	58.572	86.368	107.817
CC/SOIF Experimental Systems	91.073	74.179	143.778	203.071
TOTAL Sensors and CC/SOIF	959.667	1137.707	1600.672	1995.253
Initial Interceptors and Other KE Concepts				
Space-Based Interceptor Dev	165.000	116.000	346.286	360.412
Exoatmospheric Interceptor Dev	116.000	166.400	206.283	235.914
Endoatmospheric Interceptor Dev	106.250	115.000	168.641	116.610
Theater DefenseTechnology	67.958	75.787	139.290	149.957
Initial Interceptors Tech Base	105.571	162.368	240.234	358.986
TOTAL Initial Interceptors	560.779	635.555	1100.734	1221.879
Advanced Concepts				
CL Technology	64.800	67.582	297.558	439.299
FEL Technology	141.000	170.331	208.181	217.645
NPB Technology	67.284	57.276	49.924	49.918
ATP-FC Technology	204.243	157.686	179.723	149.759
Advanced Concepts Tech Base	201.323	154.747	280.592	390.883
CDTI/Emerging Tech	167.142	96.153	114.655	112.383
TOTAL Advanced Concepts	845.792	703.775	1130.633	1359.887
Key Technologies				
Systems Survivability	91.305	102.991	169.450	218.114
Lethality and Target Hardening	68.641	62.218	124.434	152.128
Power and Power Conditioning	97.204	99.509	205.295	236.979
Space Transportation and Support	79.558	55.000	124.809	154.750
Materials and Structures	24.890	30.731	68.428	86.061
Countermeasures	21.245	22.270	34.994	42.356
IST/SBIR	137.539	113.717	238.749	283.833
Interest Items	27.750	35.173	10.001	0.017
Technology Applications	18.468	20.277	34.227	32.415
TOTAL Key Technologies	566.600	541.886	1010.387	1206.653
System Analysis and Engineering				
SDS Phase I Engineering	45.201	63.469	125.210	155.531
SDS Engineering and Support	72.590	82.098	131.407	201.071
Theater Defense Concepts	50.500	30.605	48.922	46.720
National Test Bed	77.713	100.179	115.827	121.802
Midcourse Experiment	99.701	93.591	42.930	28.953
Test and Evaluation	138.966	76.492	117.122	160.642
TOTAL SA/BM	484.671	446.434	581.418	714.719
Management				
Program Management & Planning	115.465	141.066	140.266	145.246
SDIO HQ Management	20.026	21.000	26.394	27.456
TOTAL Management	135.491	162.066	166.660	172.702
TOTAL RDT&E RESOURCES	3553.000	3627.424	5590.504	6671.093
Military Construction	59.195	83.000	12.942	40.179
TOTAL DEPARTMENT OF DEFENSE	3612.195	3710.424	5603.446	6711.272
DOE SDI Program	353.800	336.000	311.000	276.000
TOTAL SDI PROGRAM DOD/DOE	3965.995	4046.424	5914.446	6987.272
NASA ALS	70.000	96.600	0.000	0.000

*** Due to project partitioning and realignments, there is not in all cases an exact correspondence (by PE # or Project #) with the entries shown in Table 8-1. Therefore PE #s and Project #s have been omitted from this Table to avoid confusion.**

Figure 8-2
Distribution of FY 1988 Funds by Service



individual contracting actions to DOD. This has allowed SDIO and others having access to the Federal Procurement Data System (FPDS) to have on demand very detailed information for SDI contracts valued at $25,000 or more.

The SDI Contracts Steering Group consists of representatives of each of the SDI executing agents and is chaired by the SDIO Director of Contracts. This Group meets about every 2 months to address SDI-unique contracting issues. In FY 1988, the single most important issue addressed by the Group was the implementation of Section 222 of the National Defense Authorization Act for Fiscal Years 1988 and 1989, Public Law 100-180 (the Glenn Amendment). As a result of the specialized overview provided by the Steering Group, there is now before the Defense Acquisition Review Council a case entered to amend the Defense Federal Acquisition Regulation Supplement (DFARS) to include uniform procedures to implement the Glenn Amendment. Without a forum such as our Contracts Steering Group, implementation of such important legislation would be left to various interpretations by the executing agents.

Appendix A

Soviet Strategic Defense Programs and Soviet Response to SDI

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Soviet Strategic Defense Programs and Soviet Response to SDI

This appendix discusses Soviet strategic defense programs, factors affecting Soviet response to SDI, the role of strategic defense in Soviet military strategy, and the SDIO Countermeasures program.

Soviet Strategic Defense Programs

Since World War II, the Soviets have pursued wide-ranging strategic defense programs in a clear and determined effort to blunt, in conjunction with the use of offensive forces, the effect of any attack on the U.S.S.R. The Soviet emphasis on strategic defense is firmly grounded in Soviet military doctrine and strategy. Soviet strategic defense forces are an important part of the Soviet strategic posture.

During the past decade alone, the Soviets allocated resources equivalent to approximately $400 billion to both strategic offensive and active and passive defensive programs in almost equal amounts—about $20 billion per year for each program. In the event of nuclear war, Soviet offensive forces are to:

- Destroy or neutralize as much of the enemy's nuclear assets as possible on the ground or at sea before they are launched
- Destroy or disrupt enemy nuclear-associated command, control, and communications.

Soviet defensive efforts, designed to enhance the credibility of offensive forces, are to:

- Intercept and destroy surviving retaliatory weapons—aircraft and missiles—before they reach their targets
- Protect the Party, state, military forces, industrial infrastructure, and essential working population with active and passive defense measures.

Ballistic Missile Defense

This section discusses traditional and advanced ABM technologies, antisatellite operations, and computer and sensor technology.

Traditional ABM Technologies

Soviet efforts to attain a viable strategic defense against ballistic missiles have resulted in the world's only operational antiballistic missile (ABM) system and a large and expanding research and development program.

Starting about 1978, the Soviets have been expanding and modernizing the ABM defenses at Moscow. The modernized Moscow ABM system will be a two-layer defense composed of silo-based, long-range, modified Galosh interceptors; silo-based, nuclear-armed Gazelle high-acceleration endoatmospheric interceptors (designed to engage reentry vehicles within the atmosphere); and associated engagement, guidance, and battle management radar systems, including the new PILLBOX large phased-array radar (LPAR) at Pushkino north of Moscow. This modernization will bring Moscow's ABM defenses up to 100 operational ABM launchers, the limit permitted by the 1972 ABM Treaty. This modernized system should become fully operational by the early 1990s.

The Soviet system for detection and tracking of ballistic missile attacks consists of three layers—a launch detection satellite network, two over-the-horizon radars directed at United States intercontinental ballistic missile (ICBM) fields, and two networks of large ballistic missile detection and tracking radars.

The current Soviet ICBM launch-detection satellite network and two over-the-horizon radars can provide as much as 30 minutes' tactical warning and can determine the general launch origin of the missile.

The current layer of ballistic missile detection and tracking radars consists of 11 large Hen House radars at six locations on the periphery of the U.S.S.R. These radars can confirm the warning from the satellite and over-the-horizon radar systems, characterize the size of an attack, and provide target-tracking data in support of antiballistic missile forces. Although the Soviet Union continues to maintain and upgrade this older network of ballistic missile detection and tracking systems, including launch-detection satellites and over-the-horizon radars, it is deploying a new series of large radars.

The Soviets are constructing a network of nine new LPARs that can track more ballistic missiles with greater accuracy than the existing network. Most of these duplicate or supplement the coverage of the earlier Hen House network but with greatly enhanced capability.

The growing network of large phased-array radars is of particular concern when linked with other Soviet ABM efforts. These radars take years to construct and their existence could allow the Soviet Union to move quickly to deploy a nationwide ABM defense. The degree of redundancy being built into their LPAR network is useful for early warning but has much greater utility for ballistic missile defenses.

During the 1970s, the Soviets began development of an ABM system that would allow them to construct individual ABM sites in months rather than the years required for more traditional ABM systems. Its development and testing represent a potential violation of the ABM Treaty's prohibition against the development of a mobile land-based ABM system or components. By using components of this ABM system along with the LPARs, the Soviets could strengthen the defenses of Moscow and defend targets in the western U.S.S.R. and east of the Urals.

Taken together, all of the Soviet Union's ABM and ABM-related activities are more significant and more ominous than any one considered individually. Cumulatively, they suggest that the U.S.S.R. may be preparing an ABM defense of its national territory. Such a defense could provide an important degree of protection and would fill the only missing element in their defenses.

Advanced ABM Technologies

In the late 1960s, the U.S.S.R. initiated a substantial research program into advanced technologies applicable to ballistic missile defense systems. This effort covers many of the same technologies currently being explored for the United States SDI but involves a much greater investment of plant space, capital, and manpower. The Soviet emphasis on the necessity of research into defenses against ballistic missiles was demonstrated by then Minister of Defense Grechko, shortly after the signing of the ABM Treaty in 1972, when he told the Soviet Presidium that the Treaty "places no limitations whatsoever on the conducting of research and experimental work directed towards solving the problem of defending the country from nuclear missile strikes." Moreover, General Secretary Gorbachev acknowledged on 30 November 1987 that the U.S.S.R is involved in strategic defense research. He stated, "The Soviet Union is doing all that the United States is doing, and I guess we are engaged in research, basic research, which relates to these aspects which are covered by the SDI of the United States."

Kinetic Energy Weapons. The Soviets have research programs under way on kinetic energy weapons, which use the high-speed collision of a small object with the target as the kill mechanism. In the 1960s, the U.S.S.R. developed an experimental "gun" that could shoot streams of particles of a heavy metal, such as tungsten or molybdenum, at speeds of nearly 25 km/sec in air and more than 60 km/sec in a vacuum.

Long-range, space-based kinetic energy weapons for defense against ballistic missiles probably could not be developed until at least the mid 1990s. However, the Soviets could deploy in the near term a short-range, space-based system for space station defense or for close-in attack by a maneuvering satellite. Current Soviet guidance and control systems are probably adequate for effective kinetic energy weapons use against some objects in space, such as satellites.

Laser Weapons. Scientists in the U.S.S.R have been exploring several types of lasers that may prove useful for weapons applications—the gas-dynamic, electric discharge, chemical, X-ray, free electron, excimer, and argon-ion lasers. They have achieved impressive output power levels with some of these lasers.

The Soviets appear generally capable of supplying the prime power, energy storage, and auxiliary components for their laser and other directed energy weapons programs. They have probably been developing optical systems necessary for laser weapons to track and attack their targets. They produced a 1.2-meter segmented mirror for an astrophysical telescope in 1978 and claimed that this reflector was a prototype for a 25-meter mirror. A large mirror is considered necessary for a long-range, space-based laser weapon system.

Particle Beam Weapons. Since the late 1960s, the Soviets have been exploring the feasibility of using particle beams for a space-based weapon system. They may be able to test a prototype space-based particle beam weapon intended to disrupt the electronics of satellites in the 1990s. An operational system designed to destroy satellites could follow later, and application of a particle beam weapon capable of destroying missile boosters or warheads would require several additional years of research and development.

Soviet accomplishments in particle beams, particularly ion sources and radio-frequency accelerators for particle beams, are impressive. In fact, a significant contribution to United States understanding of how neutral particle beams could be made into practical weapons was derived from Soviet research published in the late 1960s and early 1970s.

Radio-Frequency Weapons. The U.S.S.R has conducted research in the use of strong radio-frequency (high-power microwave) signals that have the potential to interfere with or destroy critical electronic components of ballistic missile warheads or satellites. The Soviets could test a ground-based, radio-frequency weapon capable of damaging satellites during the 1990s.

Antisatellite Operations

The Soviets continue to maintain the world's only operational antisatellite (ASAT) system. It is launched into an orbit similar to that of the target satellite and, when it gets close enough, destroys the satellite by exploding a conventional warhead. The Soviet co-orbital antisatellite interceptor is reasonably capable of performing its mission, and thus it is a distinct threat to United States low-altitude satellites.

During the next 10 years, the Soviets are likely to retain their current ASAT-capable systems while moving aggressively ahead in developing and deploying new ASAT systems. Their large-scale research and development efforts in laser, particle beam, radio-frequency, and kinetic energy technologies may also soon provide them with significant ASAT capabilities.

The development of a space-based laser ASAT that can disable several satellites is probably a high-priority Soviet objective. The Soviets may be able to deploy space-based lasers for antisatellite purposes in the 1990s, if their technological developments prove successful. Space-based laser ASATs could be launched on demand, or maintained in orbit, thereby reducing the time required to attack a target. This option would decrease the warning time available to the target needed to attempt countermeasures. The Soviets are also developing an airborne laser whose missions could include ASAT.

Computer and Sensor Technology

Advanced technology weapons programs—including potential advanced defenses against ballistic missiles, aircraft, cruise missiles, and ASATs—are dependent on remote sensor and computer technologies, areas in which the West currently leads the Soviet Union. The Soviets are devoting considerable resources to acquiring Western know-how and to improving their abilities and expertise in these technologies. An important part of that effort involves the increasing exploitation of open and clandestine access to Western technology. For example, the Soviets operate a well-funded program through third parties for the illegal purchase of United States high-technology computers, test and calibration equipment, and sensors.

Despite these efforts, the Soviets remain an average of 10 years behind the West in civil and industrial technology applications of computers, although military applications may be somewhat less far behind. The Soviets are also behind in sensor applications, especially with very sensitive infrared sensors employing large focal plane detector arrays. This type of sensors forms the backbone of SDI tracking, pointing, and discrimination capabilities and, also, drives some of the more stressing computer requirements.

These limitations undoubtedly prevent the Soviets from deploying defenses with the level of sophistication and capability envisioned for SDI. Nevertheless, the Soviets could take an approach, using their strengths in weapon technologies such as missiles, radar and command guidance, space launch capabilities, and even high-powered directed energy devices, and deploy systems which operate at shorter range and against corresponding smaller portions of the threat. While this would overcome some of their limitations and could have the appearance of a formidable defense, it would necessitate greater proliferation, greater reliance on ground-based and terminal defenses, and probably would still present the Soviets with difficulties in performing discrimination and in overcoming the complexities of managing the coordination of many platforms and facilities.

Air Defense

The U.S.S.R. continues to modernize and expand what is already the most extensive strategic air defense network in the world. The mission is to be carried out by a strong prepositioned national air defense force established in peacetime according to a unified concept and plan. The leadership appears to be in constant search for the optimum organizational structure of the air defense assets.

Major organizational changes instituted in 1980 transferred control of air defense aircraft, SAMs, and radars from national air defense authorities to local military district commanders. This change was probably implemented to provide battlefield commanders with greater flexibility. Even after reorganizing, the Soviets appeared to be dissatisfied with their air defense organizational structure.

More recent shifts have resubordinated surface-to-air missiles and aircraft back to the national air defense forces. The rationale may involve a desire for greater centralized control over weapons rather than the flexibility of the local commander in making certain decisions.

The Soviets have deployed a large number of strategic air defense systems with capabilities against aircraft flying at medium and high altitudes. They are now in the midst of a major effort to improve their capabilities against aircraft and cruise missiles that operate at low altitudes.

This effort includes upgrading their early warning and surveillance systems and deployment of more efficient data-transmission systems, as well as development and initial deployment of new aircraft, associated air-to-air missiles, SAMs, and airborne warning and control system (AWACS) aircraft.

Currently, the Soviets have more than 9,000 strategic SAM launchers (many with multiple launch capability) and some 10,000 air defense radars. Approximately 2,250 air defense forces interceptor aircraft are dedicated to strategic defense. An additional 2,100 interceptors assigned to Soviet Air Forces could be drawn upon for strategic defense missions. Collectively, these assets present a formidable air defense barrier.

Passive Defenses

A key element of Soviet military doctrine calls for passive defense to act in conjunction with active defense to ensure wartime operations and survival. The Soviets have undertaken a major program to harden military assets to make them more resistant to attack. Included in this program are their ICBM silos, launch facilities, and command and control centers. Additionally, the U.S.S.R has greatly emphasized mobility as a means of enhancing the survivability of military assets.

The Soviets provide their Party and government leaders with hardened alternate command posts located well away from urban centers—in addition to many deep underground bunkers and blast shelters in Soviet cities. This comprehensive and redundant network, patterned after a network designed for the Soviet Armed Forces, provides up to 1,500 hardened alternate facilities for up to 175,000 key Party and government personnel throughout the U.S.S.R.

By planning for economic survival, the Soviets hope to reconstitute vital production programs using those industrial components that could be redirected or salvaged after an attack. Reserves of vital material are maintained, many in hardened underground structures. Redundant industrial facilities are in active production. Industrial and other economic facilities are equipped with blast shelters for the work force, and detailed procedures have been developed for the relocation of selected production facilities.

Factors Affecting Soviet Response to SDI

Soviet actions in response to the SDI Program are important considerations in evaluating the overall contributions of SDI to United States security. Soviet responses are frequently hypothesized in debating the effect a strategic defense system would have on strategic stability and in arguing whether the Soviets could deploy effective countermeasures. Sometimes these hypothetical responses are put forth without adequate consideration of actual Soviet capabilities and perspectives. To avoid this pitfall, the SDIO maintains close ties with the United States intelligence community in order to better define Soviet capabilities and potential responses. In addition, SDIO maintains a Red-Blue Team effort wherein one group of innovative thinkers adopts a Soviet mindset (Red Team) and develops excursions to the baseline intelligence community estimates; then another group (Blue Team) develops potential United States counters. In these ways SDIO maintains a balanced program with prudent hedges against realistic Soviet capabilities.

It is important to maintain an appreciation of how various factors affect the likelihood of potential Soviet responses. Soviet responses will primarily be shaped by their perception of how the United States SDI Program will affect their strategies and programs. Secondly, strategic defenses have always played a major role in the Soviet's own military strategy. Thus, a close look at the extent of Soviet strategic defense programs will help to convey the importance the Soviets attach to the fact that the United States is working to initiate its own strategic defenses. The Soviet's own technological and economic strengths and weaknesses will enforce hard trade-offs among their many potential responses to the United States SDI Program. Finally, Soviet perceptions of the scope and nature of SDI, the political support it retains, as well as the likelihood of its success, will affect the nature and timing of their responses. For example, the Soviets are not likely to reshape their military forces, at great cost in time and money, unless they believe that SDI will come to fruition. The degree to which the Soviets develop countermeasures will depend upon the effectiveness of countermeasures.

Impact on Soviet Strategy and Programs

The Soviets clearly perceive SDI as a technical, political, economic, and military threat. It represents a major shift in United States defense policy aimed directly at negating the centerpiece of Soviet military might, their Strategic Rocket Forces (SRF). The importance the SRF plays in Soviet military strategy is signaled by its status as their premier service—a status it has retained since being elevated to the level of a separate armed service in 1959. Soviet writings indicate that the Strategic Rocket Forces "are the main and decisive means of achieving the goals of war since they can solve in the shortest period of time the tasks of demolishing the military economic potential of an aggressor, of destroying his strategic means of nuclear missile attack, and of crushing the main (military) groupings." The Soviets have labored long and have paid an enormous economic price to achieve ballistic missile forces adequate in size and quality to accomplish those objectives. An SDS of even modest capability would severely affect Soviet force planning which would entail a setback of many years. An SDS would also defeat Soviet nuclear targeting strategy by eroding the nuclear ballistic missile capability of the Soviet Union, a capability they feel is necessary to ensure their ability to influence the course of world events toward their desired ends. Consequently, the Soviets will continue efforts to influence or entice the United States into stopping the SDI Program.

The Soviets further perceive SDI as a major push by the United States which will widen the technological gap between themselves and the West. As a consequence, the Soviets may be expected to accelerate efforts both to acquire new technologies and to introduce those new technologies into military systems.

Considering the range of responses the Soviets must consider in attempting to preserve their present strategies, they probably perceive that SDI will impose a severe additional burden to their economy. To the extent the Soviets can influence, i.e., slow the pace of SDI, they will ease this burden.

At this time, the Soviets probably believe the United States is committed to continuing SDI in some form. Prudence dictates that they also assume that the SDI Program will, eventually, lead to deployments. They apparently have a good understanding of the elements the United States is considering for a strategic defense system and generally how they will function. This is commensurate with the extent of publication on the subject in the United States. However, they probably have considerable uncertainty regarding the degree of commitment the United States will sustain, the consequent pace of SDI, and the extent, effectiveness, and timing of defenses the United States is likely to deploy. This uncertainty multiplies the complexity of Soviet decisions for timing of responses and for trade-offs with other programs.

The Role of Strategic Defense in Soviet Military Strategy

The Soviets have a long history in the pursuit of strategic defense. They established their strategic air defense forces, the "PVO Strany" (National Air Defense, now "Voiska PVO" or "VPVO," Forces for Air Defense), in 1948, and they upgraded its status to be comparable to that of other services in 1954. It is actually ranked third in precedence after the Strategic Rocket Forces and Ground Forces and ahead of the Air Forces and Navy. Although originally created to respond to air attack, it has officially acquired the responsibility for defending the Soviet Union against ballistic missiles and satellites as well (since at least the 1950s) despite retaining the words "air defense" in the name. Official Soviet writings lay out these responsibilities explicitly and they have not been changed or otherwise deemphasized despite periods in the United States when strategic defense systems were in disfavor and the United States adopted a strategy of deterrence based primarily on offensive forces. The VPVO, in every respect, is and remains, a separate armed service for "strategic defense."

Soviet pursuit of strategic defense, through the VPVO, has been dogged: an anti-aircraft defense totally out of proportion to anything in the West; ABM defenses at Moscow which are currently being revitalized with a new two-tiered ABM system;

antisatellite capabilities such as the co-orbital system and the direct ascent capability of the Galosh (ABM interceptor for the Moscow System); and continuous and pervasive R&D effort to allow successive upgrades to existing systems, follow-on systems, and to develop systems based on new technologies such as kinetic energy and beam weapons. In addition to these efforts, the Soviet Union has maintained an extensive passive defense program, including a civil defense program. Formally instituted within the Ministry of Defense under a Deputy Minister, civil defense has been implemented on an immense scale indicative of its status as a vital element in Soviet defensive strategy. These are not merely technology programs; rather they represent an unceasing devotion toward realizing a strategy that prescribes the means to survive a nuclear war and dominate in the aftermath.

Technological Constraints

Despite outspending the United States in research and development, the Soviets remain behind in many key technology areas. The Soviet leadership itself is very pragmatic about these technological deficiencies in relation to the West. Even their most optimistic predictions do not call for attaining technical ascendancy over the West before the 21st century. Nevertheless, they are working to improve their indigenous capabilities to catch up with and surpass those of the West in basic weapon technologies. The Soviets seek to accomplish this goal by investing heavily in their own R&D base; General Secretary Gorbachev's program for economic reform calls for priorities in key high technology sectors of industry. The Soviets augment their indigenous capability by aggressively obtaining the best possible technology from any source and applying it to their military effort as quickly as possible—often much faster than their Western counterparts.

The Soviet's most noticeable weakness is in computers (hardware and software), sensors, micro-miniaturization, and electronics. Extrapolation suggests that they are weakest in tracking, pointing, guidance and control, and battle management tasks. They are in a far better position regarding kill mechanisms and heavy machine manufacturing necessary for propulsion or structures. Manufacturing high-technology items lies at the core of Soviet technological weaknesses. The Soviets can probably fabricate one or two of anything in the West. Their problem is that they cannot mass produce such items. Thus they will be able to demonstrate a better mission capability than their systems actually possess under combat conditions.

Economic Constraints

The Soviets have made a huge commitment of their nation's best resources to sustain their military buildup over the past two decades. Enormous expenditures for military programs have been a major factor behind slowing economic growth rates. The most valuable and productive resources were channeled to the Soviet military programs at the expense of living standards and investment in industries essential for economic growth. It is believed the Soviet military effort now consumes at least 15 to 17 percent of their gross national product. As a result of this increased commitment to defense, the defense industrial ministries absorb almost 60 percent of the output of the vital machine building branch of industry.

These problems have been in the making for some time, and Soviet leaders from Brezhnev period forward have acknowledged their existence. Gorbachev characterized the Soviet economy as having reached a "precrisis" stage, necessitating "in-depth, truly revolutionary transformations." Accordingly, Gorbachev has introduced or is attempting to introduce the most far-reaching economic reforms to date, which include the boldest attempt yet at decentralized economic decisionmaking, and extensive plans for industrial modernization. In seeking to accomplish his goals for economic modernization, Gorbachev is putting increasing pressure on the defense industry to provide more assistance to the civil sector.

Given SDI, the Soviets are faced with a dilemma: they are unlikely to be able to increase substantially military spending in response to SDI while fulfilling the goals of their industrial modernization program. The Soviets must carefully measure and weigh their response options. There are a wide range of potential options which the Soviets can take in attempting to nullify the effects of a United States strategic defense system, e.g., modifications to their offensive forces, additions to their offensive forces, expanding their own defenses, or enhancing the means to attack SDS elements directly. On the other hand, the Soviets have already been repressing their economy with ever expanding defense requirements. Any change will likely entail an additional economic burden, whether from the inefficiencies of changing established programs or from starting new efforts. Yet, faced with a United States SDS, they will respond in some manner. The Soviets, therefore, have some difficult choices. They cannot institute all countermeasures which have been put forth and which are technologically possible. They must pick and choose, and their schedule for implementation will probably be delayed from what we project is possible.

As a final point, in assessing the additional economic burdens, it is necessary to separate efforts already programmed in response to the Soviet's internal military requirements from totally new requirements directed specifically at responding to the United States SDI Program, and to identify programs in which progress has been paced by technology rather than funding restrictions. For example, the Soviets have had a long-standing requirement for ASAT systems and have pursued several paths toward achieving this capability. While SDI may precipitate a requirement for greater ASAT capacity, the progress in these efforts may be driven more by technological constraints than by funding.

Threat Judgments

The degree to which the Soviet Union will succeed in penetrating the defense depends on a variety of constraints and conditions, not all under their control. It is important to recognize the uncertainty associated with predicting specific Soviet responses and countermeasures. Part of the problem is uncertainties associated with intelligence data. It also reflects the uncertainty the Soviets will have in devising effective countermeasures. Generic countermeasures are easy to conceive, but they invariably involve trade-offs with system performance which can only be fully appreciated after very careful study and, eventually, with attempts at designing and testing.

SDIO Countermeasures Program

The purpose of the SDIO Countermeasures program is to provide technical evaluations of potential Soviet countermeasures and to ensure that countermeasures are taken into account by SDI system designers and technology developers. In the past year, four technical Red-Blue team analyses were active to assist SDI system concept and technology developers in understanding possible technical countermeasures: innovative architectures, space-based interceptor (SBI), ground-based midcourse interceptor (GBMI), and ground-based laser (GBL).

The innovative architecture analysis explored possible paths for the phased growth of an SDS. The SBI analysis addressed Blue systems and Red countermeasure concepts in the boost and post-boost layers of the overall strategic defense battle space. The GBMI analysis addressed the midcourse region and the GBL analysis evaluated possible countermeasures to a far-term SDS concept which included ground-based lasers and space-based relay and fighting mirrors.

Red-Blue Team Countermeasures

Red-Blue countermeasure analyses focused primarily on boost, post-boost, and midcourse countermeasure issues in FY 1988 and early FY 1989. Analyses examined the technical credibility, effectiveness, cost, and possible deployment schedules for various concepts. Simulations were employed to assess the performance of defensive systems against candidate offensive and defense suppression threats. An essential part of the program continued to be countermeasure documentation—countermeasure concepts were defined in descriptive papers and catalogued in data bases.

The Red-Blue process has resulted in an improved understanding of potential countermeasures and Soviet responses to SDI. Countermeasures have been identified and evaluated and are being considered in technology formulations and system designs.

The GBMI analysis concentrated on summarizing the activities of its second round of analyses. This round had focused almost entirely on midcourse discrimination, considering numerous sensor and countermeasure scenarios. Countermeasures found to be stressing were submitted to the Countermeasures Verification Program for examination of performance and viability.

Although there are uncertainties, we must anticipate Soviet programs across a broad front that include technologies to both counter SDS and improve Soviet ballistic missile defense capabilities. The methodology and organizational structure which SDIO has developed seeks to ensure that all likely potential responses are evaluated throughout the technical evolution of the SDI. The Red Team function has been established to see that countermeasures are taken into account in all aspects of the program. This interactive projection and evaluation of potential countermeasures is designed to assure that the SDS system architectures and technology programs are sufficiently robust to achieve mission objectives.

Strategic Red Team

The SDIO Countermeasures Program Strategic Red Team (SRT) examines technical countermeasures and tactics formulated in Red-Blue interactions for consistency with Soviet political, military, and economic style, and for the capacity of the Soviet weapon development process to produce them. The SRT also defines and assesses possible nontechnical counteractions to the SDI program. In FY 1988, the SRT evaluated seven sets of questions arising from technical Red-Blue Team interactions, produced two reports on Soviet views on SDI, and wrote a report covering a special study on space-based ASATs.

Appendix B

SDI and the Allies

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This appendix responds to the Congressional requirement to include in the annual report on the Strategic Defense Initiative (SDI) "the status of consultations with other member nations of the North Atlantic Treaty Organization (NATO), Japan, and other appropriate allies concerning research being conducted in the Strategic Defense Initiative program."

Overview

When President Reagan announced the SDI in a March 1983 speech, he emphasized that the program would be designed to enhance allied as well as U.S. security. In accordance with that mandate, the SDI Organization (SDIO) is examining technologies and concepts for defense against all ballistic missiles, regardless of their range or armament. The program strengthens the U.S. commitment to the defense of NATO and other allies and enhances our common security.

The U.S. government has been engaged in close and continuing consultations with its allies on the SDI since its inception. The United States also consults with the allies on exchanges with the U.S.S.R. at the Defense and Space Talks in Geneva and other high-level meetings that bear on the SDI Program. Those consultations will continue. Furthermore, the United States will consult closely with its allies regarding any future decision to deploy defenses against ballistic missiles.

Contacts with the allies on the SDI go well beyond consultation. In March 1985, the United States invited its allies to participate directly in SDI research. Pursuant to that invitation, several Memorandums of Understanding (MOUs) on participation in SDI research have been signed with the allies and numerous contracts and subcontracts have now been signed with foreign companies and laboratories. Approximately 60 to 70 allied firms and research institutions are performing SDI research. The SDIO has also recently signed several cost-sharing, project-specific cooperative research commitments with the allies.

Consultations With Allies on the SDI

Consultations with friends and allies on the SDI broadened and deepened throughout 1988. As in past years, such discussions are a regular feature of numerous bilateral and multilateral meetings with allied officials at all levels, both in Washington and abroad. A brief summary of some of the more noteworthy contacts follows.

President Reagan, Secretary of Defense Carlucci, and Secretary of State Shultz have discussed the Program in many of their bilateral meetings on security matters with their allied counterparts. Secretary Carlucci and Secretary Shultz also consulted with NATO defense and foreign ministers on the SDI and SDI-related arms control issues at the ministerial meetings of the NATO Nuclear Planning Group (NPG) (April and October 1988) and the North Atlantic Council (June and December 1988). Lieutenant General Abrahamson, USAF, Director of the SDIO, provided the NPG Ministers with a program status report during their October 1988 meeting.

In addition, U.S. officials consulted extensively with allied leaders, both bilaterally and at NATO, on the results of high-level meetings with the Soviet Union at which SDI was discussed. For example, this was done immediately following each round of the Defense and Space Talks in Geneva. Furthermore, senior government and industry personnel from several allied countries have visited the United States for detailed technical discussions and updates on the SDI Program. The SDI Program is sponsoring periodic advance planning briefings to acquaint government and industry representatives from selected allied nations, as well as U.S. industry, with SDI programs, initiatives, missions, and future acquisition plans. The SDI also sponsors annual, classified, multinational conferences on theater ballistic missile defense technology.

Allied Participation in SDI Research

Allied participation in SDI research—increasingly rich in technical merit through rigorous competition—is of great benefit to the United States as well as to the participating nations. Allied participation contributes to the timely attainment of SDI objectives with work of the highest quality performed at the lowest possible cost.

The United States has signed MOUs on participation in SDI research with the governments of the United Kingdom (December 1985), Federal Republic of Germany (March 1986), Israel (May 1986), Italy (September 1986), and Japan (July 1987). The MOUs are not related to specific projects; they are designed to facilitate allied participation in SDI research insofar as that is permitted under U.S. laws, regulations, and international obligations (including the ABM Treaty). While such an MOU is helpful, it is not mandatory for participation. Countries that have not signed an MOU have successfully competed for contracts.

All SDI contracts are awarded strictly on the basis of technical merit and cost, in accordance with the procurement practices mandated by the Congress. Several such provisions apply to the awarding of SDI contracts to foreign firms. The Bayh Amendment to the Fiscal Year 1973 Department of Defense Appropriations Act provides that no DOD R&D contracts may be awarded to foreign firms if a U.S. entity is equally competent to carry out the work and is willing to do so at lower cost. The Defense Appropriations Acts for Fiscal Years 1986 and 1987 prohibited any set-asides of funds for SDI research contracts awarded to foreign firms and stated that U.S. firms should receive SDI contracts unless such awards would be likely to degrade research results.

In 1987, the Congress enacted additional legislation (Section 222, National Defense Authorization Act for Fiscal Years 1988 and 1989) regarding allied participation in the SDI Program. The new legislation prohibits the award of new SDI contracts to allied entities unless certain conditions are satisfied. Such provisions shall not apply to the award of subcontracts. Since the enactment of Public Law 100-180, Section 222, 13 contracts have been awarded to foreign entities in FY 1988. Six of the contracts were awarded to foreign firms because "the contract is exclusively for research, development, test, or evaluation in connection with antitactical ballistic missile systems (ATBMs)." A seventh contract was awarded because a "foreign government or foreign firm agreed to share a substantial portion of the total contract cost." This is a contract with Israel Aircraft Industry for the Arrow experiment. The other six overseas contracts were awarded under the provisions of subsection (b) of Section 222. Cost and competency information for these awards shall be provided to the Congress separately by the Secretary of Defense.

Long-standing laws and policies governing rights to research results developed under U.S. contracts ensure that the U.S. technology base receives the benefits of all SDI research, whether performed by a domestic or foreign contractor. In conformance with these laws and policies, the U.S. government will receive rights to use the technology developed under SDI contracts. Contractor rights to use the results of their SDI research depend on security considerations and the specific conditions of each contract. These ground rules for cooperation are fully reflected in each of the MOUs and the MOAs the United States has signed on participation in SDI research.

A summary of major SDI contracts and subcontracts awarded to allied firms and research establishments between October 1985 and December 1988 follows:

- United Kingdom: $55.8 million. Optical and electron computing, ion sources for particle beams, electromagnetic rail gun technology, optical logic arrays, meteorological environment, test bed, and theater defense architecture.
- Federal Republic of Germany: $62.31 million. Pointing and tracking, optics, free electron laser technology, lethality and target hardening, electron laser technology, and theater defense architecture.
- Israel: $164.22 million. Electrical and chemical propulsion, short-wave chemical lasers, theater defense architecture, and the Arrow experiment.
- Italy: $12.11 million. Cryogenic induction, millimeter-wave radar seeker, theater defense architecture, and smart electro-optical sensor techniques.
- Japan: $1.84 million. Western Pacific theater architecture study.
- France: $13.87 million. Free electron laser technology, sensors, and theater defense architecture.
- Canada: $1.07 million. Power system materials, particle accelerators, platforms, and theater defense architecture.

- Belgium: $94,000. Theater defense architecture.
- Netherlands: $12.04 million. Theater defense architecture and electromagnetic launcher technology.

Cooperative Programs With Allies in the SDI

Cooperative research programs between the SDIO and allies are conducted in accordance with recent Congressional direction. Section 212 of the FY 1987 National Defense Authorization Act provided a $50 million ceiling on the obligation of FY 1987 SDI funds "for the joint development, on a matching fund basis, of an ATBM system for deployment with NATO allies and other countries that the United States has invited to participate in the SDI Program." Section 217 of the National Defense Authorization Act for Fiscal Years 1988 and 1989 directed that, of the funds appropriated for the SDI Program in FY 1988, "$50 million shall be made available for experiments, demonstration projects, and development relating to ATBM systems. Such projects shall be conducted on a matching fund cooperative program basis with United States allies that have signed MOUs for participation in the SDI Program."

The following programs illustrate cooperative research arrangements with allies and their industries:

- The cooperative research on electromagnetic launcher technologies with the Netherlands Organization for Applied Scientific Research, which was discussed in the FY 1988 Report to the Congress on SDI, is proceeding as scheduled. The electromagnetic launcher leased to the Dutch has been assembled in the Netherlands.
- The SDIO signed a cost-share contract with a Japanese firm for analysis of a theater missile defense architecture for the Western Pacific theater. This firm, which will underwrite a portion of the cost of the contract, will assess the unique requirements associated with the defense of U.S. and allied assets in the Western Pacific against attack by medium- and short-range ballistic missiles.
- The United States, under a cost-sharing Letter of Offer and Acceptance with the U.K. MOD, will undertake a joint cooperative program, known as the Extended Air Defense Test Bed (EADTB). The EADTB is designed to provide support for extended air defense planning, concept analysis, doctrine development, and battle plan development.

The SDIO is engaged in exploratory discussions with allies to determine other areas of mutual research interest, to be pursued in similar types of cooperative arrangements.

Defense Against Shorter-Range Ballistic Missiles

The United States, NATO, Israel, and Japan are actively addressing the need for antitactical ballistic missile (ATBM) defenses in light of the tactical missile threat faced by our allies and U.S. forces overseas. NATO is engaged in a number of studies to further define the threat and to determine what measures should be undertaken to meet that threat.

SDIO allocated $126 million, including $50 million in cooperative funds, in FY 1988 for research on theater missile defense concepts and technologies. Such ATBM efforts, particularly via cooperative arrangements, have been supported by the Congress.

In its ATBM efforts, SDIO has worked very closely with the U.S. Army. The U.S. Army, which has been designated as the lead service for DOD's overall ATBM program, continues to organize overall support for the ATBM. At the same time, the SDI continues to examine technologies and concepts for active defenses against ballistic missiles of all ranges and armaments, including those shorter-range systems that directly threaten our friends and allies and are not proscribed by the INF Treaty. The Army's Strategic Defense Command (SDC) has been designated as the SDI executive agent for the management of this theater defense portion of the SDI Program. The advances in technology achieved in the SDI Program will be made available to the Army's ATBM program through the SDC.

SDI research awards for theater defense have included architecture studies—performed by the governments of the United Kingdom and Israel and by several multinational contractor teams—as well as specific technology programs and experiments. The theater architecture studies, together with follow-on activities to be performed in theater test beds, will contribute importantly to our collective thinking on the vital issue of ensuring NATO's and other allies' security against the threat of Soviet and a panoply of third world shorter-range ballistic missiles over the near and longer term.

Summary of Allied Participation and Cooperation

Allied scientific excellence and technical prowess have been, and continue to be, demonstrated through their contractual efforts and cooperative research projects. Their technical contributions relate to both the defense against strategic ballistic missiles and theater missile defense.

There have been many notable achievements. During the past year, for instance, Culham Laboratories in Great Britain achieved the highest-brightness, continuously operating ion source to date for neutral particle beams (NPBs). This achievement is particularly significant because it will serve as the basis for further development of the NPB. In another case, SDIO will use the West German-built Shuttle Pallet Satellite (SPAS) as a carrier for the infrared sensor in the so-called Infrared Background Signature Survey (IBSS), which will measure, inter alia, orbiter plumes, the earth limb, the earth background, and the orbiter environment. The SPAS vehicle, designed for payload flexibility, high strength, and light weight, has flown successfully on two previous missions and is manifested for IBSS on a future Shuttle flight.

Currently, trends in allied involvement in the SDI Program are toward more theater missile defense-related activities, test bed and technology experiments, and other cooperative activities of mutual interest. The continued participation and cooperation of the allies in the SDI will promote greater scientific understanding and technological mastery of the ballistic missile defense problem. Through these multinational efforts, SDIO's theater and strategic missile defense technologies will continue to advance. Additionally, such participation and cooperation will provide a sound basis for U.S. and allied leaders to make informed decisions about their common security.

Appendix C

SDI Compliance With the ABM Treaty

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SDI Compliance With the ABM Treaty

This appendix addresses the portion of Section 231 of the FY 1988-89 National Defense Authorization Act which requests "a statement of the compliance of the planned SDI development and testing program with existing arms control agreements, including the Antiballistic Missile [ABM] Treaty."

Introduction

The 1972 ABM Treaty addresses the development, testing, and deployment of different types of ABM systems and components. It should be noted that nowhere does the ABM Treaty use the word "research." Neither the United States nor the Soviet delegation to the SALT I negotiations chose to place limitations on research, and the ABM Treaty makes no attempt to do so. The United States made it clear during the ABM Treaty negotiations that development commences with the initiation of field testing of a prototype ABM system or component. The United States had traditionally distinguished "research" from "development" as outlined by then United States delegate Dr. Harold Brown in a 1971 statement to the Soviet SALT I delegation. Research includes, but is not limited to, conceptual design and laboratory testing. Development follows research and precedes full-scale testing of systems and components designed for actual deployment. Development of a weapon system is usually associated with the construction and field testing of one or more prototypes of the system or its major components. However, the construction of a prototype cannot necessarily be verified by national technical means (NTM) of verification. Therefore, in large part because of these verification difficulties, the ABM Treaty prohibition on the development of sea, air, space, or mobile land-based ABM systems, or components for such systems, applies when a prototype of such a system or its components enters the field testing stage.

The ABM Treaty regulates the development, testing, and deployment of ABM systems whose components were defined in the 1972 Treaty as consisting of ABM interceptor missiles, ABM launchers, and ABM radars. Systems and components based on other physical principles (OPP) are addressed only in Agreed Statement D to the Treaty as "ABM systems based on other physical principles and including components capable of substituting for ABM interceptor missiles, ABM launchers, or ABM radars." In order to fulfill the Treaty's basic obligation not to deploy ABM systems or components except as provided in Article III, this agreed statement prohibits the deployment of systems or components based on OPP, but does not proscribe the development and testing of such systems, regardless of basing mode. The SDI Program will continue to be conducted in a manner that fully complies with all United States obligations under the ABM Treaty.

Research and certain development and testing of defensive systems are not only permitted by the ABM Treaty, but were anticipated at the time the Treaty was negotiated and signed. Both the United States and the U.S.S.R. supported this position in testimony to their respective legislative bodies. When the Treaty was before the United States Senate for advice and consent to ratification, then Defense Secretary Melvin Laird advocated, in his testimony, that the United States "vigorously pursue a comprehensive ABM technology program." In a statement before the Presidium of the Supreme Soviet, Marshall Grechko said the ABM Treaty "places no limitations whatsoever on the conducting of research and experimental work directed toward solving the problem of defending the country from nuclear missile strikes."

Existing Compliance Process for SDI

DOD has in place an effective compliance process (established in 1972, after the signing of the SALT I agreements) under which key offices in DOD are responsible for overseeing SDI compliance with all United States arms control commitments. Under this process the SDI Organization (SDIO) and armed services ensure that the implementing program offices adhere to DOD compliance directives and seek guidance from offices charged with oversight responsibility.

Specific responsibilities are assigned by DOD Directive 5100.70, 9 January 1973, Implementation of SAL Agreements. The Under Secretary of Defense for Acquisition, USD(A), ensures that all DOD programs are in compliance with United States strategic arms control obligations. The Service secretaries, the Chairman of the Joint Chiefs of Staff (JCS), and agency directors ensure the internal compliance of their respective organizations. The DOD General Counsel provides advice and assistance with respect to the implementation of the compliance process and interpretation of arms control agreements.

DOD Instruction S-5100.72 establishes general instructions, guidelines, and procedures for ensuring the continued compliance of all DOD programs with existing arms control agreements. Under these procedures, questions of interpretation of specific agreements are to be referred to the USD(A) for resolution on a case-by-case basis. No project or program which reasonably raises a compliance issue can enter into the testing, prototype construction, or deployment phase without prior clearance from the USD(A). If such a compliance issue is in doubt, USD(A) approval shall be sought. In consultation with the DOD General Counsel, Office of the Assistant Secretary of Defense for International Security Policy, and the JCS, the USD(A) applies the provisions of the agreements, as appropriate. Military departments and DOD agencies, including SDIO, certify internal compliance quarterly and establish internal procedures and offices to monitor and ensure internal compliance.

In 1985, the United States began discussions with allied governments regarding technical cooperation on SDI research. To date, the United States has concluded bilateral SDI research Memorandums of Understanding with the United Kingdom, the Federal Republic of Germany, Israel, Italy, and Japan. All such agreements will be implemented in a manner consistent with United States international obligations, including the ABM Treaty. The United States has established guidelines to ensure that all exchanges of data and research activities are conducted in full compliance with the ABM Treaty obligations not to transfer to other states ABM systems or components limited by the Treaty, nor to provide technical descriptions or blueprints specially worked out for the construction of such systems or components.

SDI Experiments

All SDI field tests must be approved for ABM Treaty compliance through the DOD compliance process. The following major experiments, all of which involve field testing, have been approved and are to be conducted during the remainder of FY 1989 and during FY 1990-91: JANUS; the Delta Star Experiment; the SKYLITE test program which utilizes the Mid-Infrared Advanced Chemical Laser (MIRACL) and the SEALITE Beam Director; the Laser Atmospheric Compensation Experiment (LACE) and Relay Mirror Experiment (RME) space tracking and pointing experiments; the neutral particle beam accelerator experiment called BEAR (Beam Experiment Aboard Rocket) the Kinetic Kill Vehicle Integrated Technology Experiment (KITE) test in the High-Endoatmospheric Defense Interceptor (HEDI) program; the Airborne Optical Adjunct (AOA) infrared experiment; the Starlab tracking and pointing experiment; Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS); and the Arrow antitactical missile program.

The following major experiments have been approved for later years, subject, in some cases, to review of a more completely defined experiment: Midcourse Sensor Experiment (MSX); Extended Range Interceptor (ERINT) program; Ground-Based Radar Experiment (GBR-X), formerly called the Terminal Imaging Radar; HEDI; the ground-based free electron laser; and the Zenith Star space-based laser experiment.

The Boost Surveillance and Tracking System (BSTS) experimental program has been reviewed in the past but will require additional review as it becomes more fully defined. An orbital flight experiment of a device of minimal capability and the flight of a BSTS satellite are projected.

In addition, the following data collection or other experiments or programs which have not been considered as major experiments continue to be approved: Queen Match; Three-Color Experiment/Visible Ultraviolet Experiment; Optical Airborne Measurement Program; Red Gemini; IBSS (Infrared Background Signature Survey); CIRRIS (Cryogenic Infrared Radiance Instrumentation for Shuttle) 1A; Excede III; Spirit II; SPEAR (Space Power Experiments Aboard Rockets) II; and Royal Shield II.

The following programs have approved activities that are not considered to be in field testing during the remainder of FY 1989 and FY 1990-91: Alpha/LAMP/LODE, hypervelocity gun (HVG), Space-Based Surveillance and Tracking System (SSTS), Ground-Based Surveillance and Tracking System (GSTS), Space-Based Interceptor (SBI), and BSTS. Also, the National Test Bed/National Test Facility has been determined to be compliant with the ABM Treaty.

Currently, no experiment has been approved which would not fall within the categories used in Appendix D to the 1987 Report to the Congress on the SDI. Changes to previously approved experiments or new experiments resulting from the restructuring of the SDI Program require compliance review.

Appendix D

SDI Technology and Other Defensive Missions

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SDI Technology and Other Defensive Missions

This appendix responds to the portion of Section 231 of the FY 1988-89 National Defense Authorization Act that requests details on which Strategic Defense Initiative (SDI) technologies can be developed or deployed within the next 5 to 10 years to defend against significant military threats and help accomplish critical military missions.

SDI Research and Its Use in Other Defense Systems

Certain SDI technologies have been identified that may have applications for other U.S. strategic and conventional defense systems. These include developing technologies behind the so-called smart weapons, the Advanced Tactical Fighter, naval air and surface weapon systems, and F-16 aircraft. Also included are the use of SDI electromagnetic gun technology in the design of new defense systems and the application of SDI-developed materials processes in the manufacture of stronger and lighter gun barrels. In fact, specific SDI technologies are currently being considered for incorporation into the research and development of defense systems.

The Joint SDI Defense Technology Applications Initiative Panel

In December 1987, the Department of Defense Defense Resources Board (DRB) requested that a study be conducted to evaluate the potential of SDI technology to be used in other defense-related research and development efforts. The DRB implementation review group convened to complete the study recommended in its earlier report, "Service Adaptation/Utilization of Strategic Defense Initiative Related Technologies." In that report the DRB sought to "establish an evolutionary SDI-military applications panel to identify subsystem, componentry, and technology options for managers of near-term programs" and also recommended "complementary technology approaches for long-term service requirements."

As a result of this study, the DRB approved the establishment of a Joint SDI Defense Technology Applications Initiative (JDAI) panel as a vehicle for sharing SDI technology with other DOD agencies. The chairman of the DRB, the Deputy Secretary of Defense, designated the Director, Defense Research and Engineering (DDR&E), to form the panel. DDR&E, in turn, appointed the Director of Technology Applications, SDIO, to chair the JDAI panel whose membership is to be comprised of representatives from OSD, the Services, and the Joint Chiefs of Staff.

The JDAI panel has examined a number of defense programs in its efforts to identify where SDI-developed technologies can be shared to help meet the operational requirements of ongoing DOD research and development work. DOD programs being examined include the Air Defense Initiative (ADI), the Balanced Technology Initiative (BTI), strategic force modernization, space systems, and science and technology programs. Other programs the JDAI panel is reviewing in its evaluation process include those focusing on the hardening and survivability of conventional defense systems; communication and information technologies; and test facilities, resources, and instrumentation.

These JDAI panel activities are an outgrowth of legislation and other initiatives undertaken to use technologies developed in military research and development programs as a source of innovation for other public and private sector research and development efforts. The National Defense Authorization Act of 1987, for example, states that the Secretary of Defense shall "encourage, to the extent consistent with national security objectives, the transfer of technology between laboratories and research centers of the Department of Defense and other federal agencies, state and local governments, colleges and universities, and private persons in cases that are likely to result in the maximum use of such technology."

The JDAI panel has met six times. Initial meetings were devoted to acquainting the panel members with the SDI technology base and introducing them to the methodologies available for cross-matching of service technology needs with potential solutions from SDI research and development.

A prime tool used in this cross-matching process is the Technology Applications Information System (TAIS), the modem-accessible computerized data base that provides interested parties with information on SDI-developed technologies that may have potential value and use for other defense-related research and development efforts. (A detailed discussion of TAIS is included in Appendix E, SDI Technology Applications.)

The JDAI panel also serves as a contact vehicle by which DOD program managers can avail themselves of the expertise provided by the panel's members and services offered by the SDIO Office of Technology Applications. Such activities include cross-matching a user's request for information with SDI technologies when that request is of a classified nature, expediting the process by which SDI technology information is made available to other DOD programs, and establishing new or more effective lines of communication to accelerate the SDI technology transfer process.

As part of JDAI panel activities, a number of pilot projects have been started to identify and incorporate SDI technologies into research and development activities undertaken by the Services and the Defense Advanced Research Projects Agency (DARPA). The results of this work are summarized in Figure D-1.

Figure D-1
Joint SDI-Defense Application Initiative Activities

Requestor	Source	Type	Results*	Remarks
Army	Future Army Weapon systems and associated technology barriers	Forward area air defense system (FAADS)	200	Provided to Army laboratory command staff
		Advanced antitank weapon system—heavy	230	
		Light helicopter experimental (LHX) family of helicopters	128	Provided to LHX program manager
Navy	Space ware and naval air mission are requirements	24 generic mission technologies	79	Provided to Navy, Chief of Naval Technology
	Navy Balanced Technology Initiative (BTI)	20 top BTI technologies for FY 1989	99	Provided to Navy BTI manager
	Navy EM catapult program	EM-related technologies	12	Provided to Lakehurst, NJ, program manager
Air Force	Air Force Project Forecast II future system needs	Supersonic vertical/short takeoff and landing (V/STOL) fighter	219	Provided to Air Force JDAI panel members
		Hypersonic vehicle	460	
		Super Cockpit	140	
	Strategic offense	BM/C3, strategic relocatable targets	104	SAC and Joint Strategic Target Planning System (JSTPS) to review
Defense Advanced Research Projects Agency	Balanced technology program	Smart weapons program	43	Provided to DARPA program manager
	Strategic Technologies office	Strategic relocatable targets	58	
Classified		Five technology areas	122	Provided to appropriate Service staffs

* The number of cross-matched SDI technologies that could meet requirements of the DOD program in question.

The panel has identified U.S. Army weapon system requirements that could be met with SDIO technologies. The U.S. Army Laboratory Command (LABCOM) supplied technology barriers that must be hurdled to develop technologies integral to future U.S. Army weapon systems. Using this approach as a baseline for its work, SDIO assisted LABCOM in identifying technologies currently being developed through SDI research that may be of value to LABCOM in R&D on future U.S. Army weapon systems. In addition to using data supplied by U.S. Army LABCOM, SDIO provided the U.S. Army light helicopter experimental (LHX) development manager with details of SDI projects and points of contact in those technology areas determined by the U.S. Army to be applicable to the LHX and similar programs.

The U.S. Navy Office of Naval Technology provided technology requirements needed to satisfy future U.S. naval air and surface mission areas. SDIO cross-matched these requirements with SDI projects and then provided the U.S. Navy with a listing of specific projects managed for SDI in similar technology areas. SDIO also cross-matched a series of technologies drawn from a listing of U.S. Navy Balanced Technology Initiative (BTI) candidates to be funded in fiscal year 1989 and provided project information and sources of SDI research from which the BTI program manager could draw in efforts to develop leading-edge technologies for BTI. (BTI is a Congressionally funded initiative for the research and development of technologies that could be used to strengthen the United States' conventional military posture.) The U.S. Navy program manager for the development of aircraft carrier catapult systems that use electromagnetic technology was provided abstracts and points of contact for SDI research on electromagnetic launcher technologies.

SDIO reviewed the U.S. Air Force's Project Forecast II, a study initiated to project U.S. Air Force strategic and tactical requirements into the 21st century, in order for the U.S. Air Force to identify top priority future systems. SDIO then cross-matched the required technology advances for three selected programs with similar SDIO technology projects and provided this information to the U.S. Air Force representatives of the JDAI panel.

The U.S. Marine Corps was provided information to explore the potential for application of new Sullivan process materials to armor, suspension components, and engine enhancements for amphibious assault craft. This material is being considered because of its light weight and strength. The Sullivan process is a method developed that extends material properties using a carbon matrix or carbon fiber coating technology originally investigated under an SDI Small Business Innovative Research contract.

The Sullivan materials process has the potential for application to gun barrels that can be reduced in weight by over 60 percent with vapor deposition linings that may also increase barrel life significantly. The lighter weight barrels could, for example, improve the reaction of the U.S. Navy Phalanx gun system by reduction in mass and thus an increase in the slew rate of the system with attendant lower wear on system components and bearings.

Based on information the DARPA program manager for smart weapons provided to the JDAI panel, SDI technologies were identified that may be of assistance in the research and development of smart weapons. Areas of potential application include inertial sensors, projectiles, and small, powerful microprocessors.

SDIO worked with Service managers for other classified projects to search for SDI technologies in several generic areas that could be used in the research and development of the systems of interest. This approach provided security to the eventual end system user.

A number of other possible uses of SDI technology also exist. For example, advances in the state of the art of capacitor storage capability and reduction in size have potential use in aircraft backup power systems, mobile power for electromagnetic gun artillery systems, and distributed shipboard power systems. Precision, all-weather microwave range doppler imaging with fine resolution, faster broad area coverage, and penetrating power for subsurface imaging are being developed that could detect covert operations and hidden sites and be used for arms control treaty verification purposes. New inertial measurement unit (IMU) technologies have been developed for ground- and space-based interceptors that are smaller, lighter in weight, and more accurate than current IMUs. This technology may also be used in armored vehicles, artillery shells, tactical missiles, aeronautical systems, and strategic missiles. Laser protective materials, developed to protect SDS sensors, are being translated into applications for protective lenses that can be used by pilots and other military personnel subject to combat laser blindness.

Electromagnetic Guns and New Defense Systems

SDI electromagnetic gun technology is now being considered for use in the design of a new generation of defense systems, including the following:

- An aircraft carrier catapult system that reduces power demands on existing nuclear power plant systems and extends their operational life
- Long-range land and naval artillery systems that could extend the range of current conventional munition artillery projectiles by three to four times
- Shipboard and air-based air defense gun systems that use rapid-fire, hypervelocity projectiles which provide a more efficient, longer-reach, defensive shield for naval ships against attacks by fast air-launched or submarine-launched antiship missiles
- The use of electromagnetic guns as flexible, mobile launching devices for satellites in which tactical force commanders need to replace critical surveillance and communication assets that may be knocked out by enemy antisatellite weapons in wartime

- The use of hypervelocity projectiles as antisatellite weapons which can be fired from ground-based installations to intercept enemy satellites.

Defense Against Tactical Missiles

Memorandums of Agreement to implement the directions of Deputy Secretary of Defense Taft have been agreed to by SDIO and the Army and by their respective executive agencies, the Strategic Defense Command (SDC), and the Army Material Command. The U.S. Army's SDC has been designated as the SDI executive agent for managing the tactical missile defense portion of the SDI Program.

Although allied and U.S. Army ATM efforts are separate from the SDI research program, they remain closely coordinated. Furthermore, the United States fully expects that technologies and concepts under examination for SDI can make a substantial contribution to theater defenses. The Memorandum of Understanding (MOU) completed by the Army and SDIO will facilitate this sharing of technology. It is also anticipated that conventional forces in general will benefit greatly from advances and achievements in SDI research.

The theater defense program combines architecture studies, technology research, and test bed development to form the cornerstone of an essential set of layers in the global defense against ballistic missiles. The concept definition and architecture studies continue to be conducted through both government-to-government agreements with our allies and U.S.-managed procurements with multinational contractor consortia. These studies address candidate architectures, technology requirements, interfaces with existing defensive capabilities, and technology risks within current allied and American technology programs. Additionally, this effort will direct the theater test bed program which will develop the capability to simulate and evaluate the contributions of various theater architecture systems and elements to a layered defense. The theater defense program defines the mission objectives and derives candidate architectures for the NATO region and other regions against the threat of theater ballistic missiles. The principal goal of this effort is to focus theater defense activities in a coherent and comprehensive manner which will be appropriate to the development and exploitation of necessary technologies.

Architecture Studies

Theater defense architecture study contracts for the United Kingdom, Israel, and Western Pacific have been awarded, and each participant was provided an initial threat scenario and has been or will be requested to derive a specific regional threat. From their generated threats, the participants, utilizing an iterative system engineering process, allocate requirements, specifications and cost to the various elements (weapons, sensors, battle management command, control, and communications [BM/C^3] of the theater defense system.

Theater Defense Missile Architecture Studies

The Theater Missile Defense Architecture Studies (TMDAS) established and evaluated several alternate evolutionary architecture concepts to provide a capability against the theater missile threat. This effort is being managed in several phases. During Phase I, which has been completed, the mission requirements for a theater defense system to counter the projected near-term, mid-term, and far-term threats posed by tactical ballistic missiles were identified. Candidate system architectures were also identified and evaluated. These architectures considered a mix of active defense, passive measures, and counterforce. Critical issues were identified and a Phase II study plan was developed.

The Phase IIA effort, which also has been completed, accomplished a detailed concept definition for the selected architecture to include system and subsystem requirements and specifications (military standard level A), identification of interface requirements, requirements balancing system/subsystem elements, and identification of detailed BM/C^3 and support requirements. Additional products from this phase were deployment plan, operational deployment concept, and life-cycle cost estimates. The Phase IIA effort was designed against the near-term pre-INF threat. Phase IIB which is in progress, will modify the Phase IIA architectures to reflect the near-term post-INF threat and will provide briefings and support to NATO panels that are defining theater defense requirements and architectures. Phase IIB will also result in identification of technology requirements and experiments. The studies are executed by five international contractor consortia.

U.S.–U.K. Bilateral Architecture Studies

The goal of these studies was to define, from a U.K. point of view, an evolutionary European missile defense architecture for the near, mid, and far term to counter nuclear-tipped ballistic threats in a pre- and post-INF Treaty environment. The effort includes the definition of missions, requirements, and system functions, and the detailed development of the functional, operational, and performance requirements.

The architectures are designed to be evolutionary in nature and also to assess the potential linkage of a candidate theater defense system with the U.S. strategic defense system. The effort will identify critical technologies, cost drivers, risk, logistic issues, developmental priorities, potential vulnerabilities, deployment issues, and problems. Strategies for implementing and deploying the architectures will be identified. The emphasis in this stage is to understand the implications of, and develop defensive constructs against, ballistic missiles with ranges in excess of those classed as short-range (less than 500 kilometers). These threats are nuclear armed and, in the post-INF treaty era, are in fact retargeted Soviet ICBMs and SLBMs used at less than intercontinental range.

Architecture Study for Middle East Theater Defense

The completed study will develop a threat assessment [illegible] icy and strategy followed by theater defense mission requirements [illegible] dle East threat and achieve policy objectives. The study will identify all the functions that a theater defense system or major component must perform and the characteristics that a thoroughly reliable system must have. It is expected that more than one candidate system, processing method, etc., shall ultimately evolve from this study.

Western Pacific Basin (WESTPAC) Architecture Study

The objective of this study is to develop a complete characterization of the missile threat to the Western Pacific region, emphasizing the defense of Japan and the protection of associated and other territories in the area of interest to the United States. Further, the study will identify unique architectural elements needed to provide this defense based on the contractor's analysis of the threat and of defense-related advanced technology concepts. Technical and political issues are to be identified insofar as they affect the development of candidate architectures. If appropriate, the study will consider the potential relationships between the elements of U.S. strategic defense system architectures and the elements of Western Pacific regional architectures. The product will be fully evaluated architectures that can be used as a basis for operational and system performance specifications. In the formulation of architectures, consideration should be given to building upon existing forces and infrastructure, including planned and programmed improvements. Critical components, subsystems, and system technologies to meet these objectives shall be identified.

Theater Test Bed Programs

This section discusses theater test bed programs such as the Extended Air Defense Test Bed (EADTB), the Israeli Test Bed, and Invite, Show, and Test (IS&T) project.

Extended Air Defense Test Bed

The EADTB will consist of a series of computer simulation (system emulation) facilities located in the United States and Europe. These facilities will support the concept analysis, design, and evaluation of theater defense architectural concepts for the European theater, including coordination with the U.S. strategic defense system. Each facility (test bed node) will function in a stand-alone configuration, it will also be capable of working in a network configuration with other test bed nodes while interfacing with the U.S. National Test Bed (NTB). The first segment will consist of nodes in the United States and the United Kingdom, to be followed later by continental European national nodes and/or a NATO/SHAPE node.

The EADTB will represent a complete active defense architecture that may include multiple weapons systems (not just missile interceptors) and multiple sensors (ground, air, and space based) that can be deployed in NATO or by others in support of NATO. Test bed architectures will include simulations necessary to model the BM/C^3 function as related to each defensive tier from the active defense unit to the national or theater command. Key BM/C^3 functions, algorithms, interfaces, and responses will be emulated to simulate each architecture as integrated into the NATO Air Command and Control System.

The threat to NATO posed by tactical or air-breathing systems, manned and unmanned aircraft, as well as SRBMs, IRBMs, etc., will be addressed. Within NATO, the EADTB must accommodate variations of expected threat applications that are regionally driven. Interactions between theater defense elements and strategic defense systems must be evaluated as the NATO theater defense and the U.S. SDS develop. The multiple level considerations that the EADTB must accommodate are summarized in Figure D-2.

Figure D-2
Multiple Level Considerations for EADTB

Level	**Alliance (Theater)**	**Multilateral (Regional)**	**National (Local)**
Issues	Multiple issues driven by geography and national will Resources (manpower and funding)	Differences are driven by the threat to the region Resources (manpower and funding)	Differences are driven by equipment evolution Resources (manpower and funding)
Organization	SHAPE CINCEUR SHOC	CENTCOMM CACC SFP CRC SAMDC	Patriot battalion Hawk battalion Roland battalion MSAM battalion
Constraints	Treaties, international agreements	ACCS traffic volume, outdated technology	Existing comm links nationwide weaponry

Analytical results derived from EADTB experiments will provide the basis for extended air defense system decisions and for determining the resources (funds and personnel) needed to meet extended air defense goals in a combined warfare environment.

Program managers use the test beds for concept validity and architecture selection for senior decision makers in the several cooperating nations. Operational military planners will use the facilities to address issues relating to BM/C^3 interfaces and interactions with existing European air-defense systems, options for allowable rules of engagement and battle management doctrine, the proportion and limitations for humans and machines in decisionmaking during battle, and personnel training requirements. Military laboratories and industrial design teams will explore alternative solutions to technical problems, design issues, and internal and external system interfaces.

Israeli Test Bed

The Israeli Test Bed will be capable of simulating theater missile defense in the Middle East theater. The initial test bed capability will consist of an integrated simulation of the near-term threat and alternative defense architectures; it must be able to evolve change to support further evaluation of the improved or modified defense system elements with regard to responsive threats. It must provide for the evolution of the man-machine interface in defense architecture designs as well as the future capability to integrate actual systems in a "hardware-in-the-loop" for real-time analysis of hardware capabilities in a theater missile defense architecture. The Israeli Test Bed will include the capability to perform and evaluate (1) interfaces between weapon systems; (2) man-in-the-loop responses to representative short-range ballistic missile attacks; (3) performance of battle management in a saturation attack scenario; and (4) the utility of different combinations of sensor data as inputs.

Invite, Show, and Test

The IS&T project solicits mature technologies which will support full-scale development decisions for systems and subsystems for an interim theater defense capability. Test articles are solicited from U.S. and allied industries through a broad agency announcement which identified three categories for the active components of theater defense: sensors, destruction mechanisms, and related BM/C^3 systems.

IS&T support includes all activities required to conduct tests and evaluate IS&T test articles; it includes test planning and documentation, defining measures of effectiveness, test integration, test conduct, coordinating targets, data analysis and reduction, modeling and simulations, and data evaluation extrapolation to assess the theater defense utility of all IS&T participants.

Air Defense

The air defense mission encompasses surveillance, warning, interception, and identification or negation of unknown aircraft that penetrate the air defense identification zone. Systems that contribute to that mission in the continental United States include the Joint Surveillance System network of Air Force and Federal Aviation Administration radars, the North American Warning System of radars across Alaska and Canada, Airborne Warning and Control System (AWACS) aircraft, and those fighter-interceptors on continuous alert. These systems will be augmented by the Over-the-Horizon Backscatter (OTH-B) radar network, which is scheduled to be operational in the early 1990s. The technical promise of SDI could significantly improve air defense mission efficiency and effectiveness, especially against future threats.

Tactical air defense in a theater of operations includes sensors such as the AWACS and mobile ground-based radars. These provide early warning and engagement control of Air Force air defense and Army anti-aircraft surface-to-air missile (SAM) systems such as Patriot and Hawk. This leads to a highly decentralized command and control environment that is today constrained by limitations in current BM/C^3 systems.

North American air defense assets operate as a system, with one type of surveillance asset compensating for the deficiencies of others. Interceptor aircraft are necessary because fixed surveillance sensors cannot identify all tracks. In some cases, AWACS aircraft and interceptors actually perform surveillance when transient gaps occur in radar coverage. If fixed or aircraft-based sensors had greater capability, interceptors could perform more critical missions. Improvements in sensor range, data processing, and operating efficiency would greatly facilitate the air defense mission.

Because aircraft can be diverted to many possible targets, it is difficult to discern the character of an air-breathing attack. However, broad patterns of mass raids can be revealed if information from multiple sensors can be assimilated simultaneously. Advances in survivable communications and distributed computation could significantly improve raid recognition, attack assessment, and efficient assignment of interceptors.

Theater air defense operations depend on limited sensor and BM/C^3 architectures, which are in turn affected by electronic countermeasures and raid size. The addition of adjunct sensors using a variety of physical principles would ensure sustained operation and preclude being hampered by a simplified development of countermeasures. Robust BM/C^3 and data processing systems are needed to ensure that adequate theater air defense operations are maintained.

Maritime Operations

The global maritime operations of U.S. naval units and fleets in peacetime and wartime are critically dependent on surveillance, communications, and the ability to intercept hostile forces beyond the range at which they can actively threaten fleet units. The U.S. Navy is confronted by a Soviet maritime threat of growing size and sophistication, a multidimensional force that possesses demonstrated capability for surveillance, track, and attack from space, air, surface, and subsurface platforms. Existing Navy defenses involve multiple layers and redundant systems, much in the manner proposed for a layered strategic defense against ballistic missiles.

Conventional Forces

For conventional ground force operations in a European general war, the Soviets have deployed a vast array of weapons to provide massive firepower. This array includes tanks, mobile artillery, and armored personnel carriers as well as sophisticated attack helicopters. These weapons are designed to provide the mobility and firepower necessary to overwhelm NATO forces without resort to nuclear weapons.

As a counter to this Soviet-Warsaw Pact capability, conventional NATO forces require an infusion of new technologies to provide improved capabilities in the areas of firepower, fire control, command and control, communications, and improved power supplies to enhance the mobile operations of advanced weapons.

The SDIO is developing a range of advanced technologies which could be used in developing advanced weapons, support systems, and control systems for conventional forces. For example, lightweight, rapid-fire hypervelocity gun technologies could provide significant improvements in anti-armor, anti-aircraft, and fleet defense operations. These kinds of systems could be capable of rapid, lethal response to conventional attack, especially when coupled with low-cost guided hypervelocity projectiles. These technologies may provide the synergy needed to develop an effective long-range deterrent to conventional threat systems.

In addition, the development of high power-density power supplies could provide a significant benefit to the modern conventional force, especially command and control and support elements. The technical improvements being made in communications, battle management, and resource allocation also are generating greater demands on the design of effective power supply systems that can provide sufficient power with low noise and/or thermal signatures. Lightweight, quiet power systems would contribute to the reduced signature of critical units and thus enhance survivability while meeting power needs.

The ability to engage more than one target at a time is being developed through advances in computer-aided and controlled multitarget fire control systems. This ability would enhance the battle management functions of all forces and enhance their efficiency in the use of resources.

In another critical area, the SDI Program is developing technologies to automate the collection, fusion, and processing of massive amounts of intelligence data on a near real-time basis. The application of expert systems will further facilitate processing the data to allow force structures to be categorized and tracked. These developments can ensure the timeliness and availability of reliable intelligence to keep pace with increased application of heliborne and mobile forces on a battlefield.

Space Defense

The defense of U.S. and allied military space assets has become increasingly important as the Soviets maintain their present co-orbital ASAT interceptor, develop large-scale directed energy facilities with satellite-attacking capability and maintain a potential direct-ascent ASAT capability with their deployed ABM interceptor (the nuclear-tipped Galosh). The SDIO is fully committed to researching systems that will remain effective in the face of these dedicated efforts to defeat them. We are funding major investments in the technologies needed to enhance the survivability of space- and ground-based elements of any future ballistic missile defense system.

Tactical Warning and Attack Assessment

The tactical warning and attack assessment (TW/AA) is crucial information that decision makers require to allow them to respond adequately to a ballistic missile attack. This function is essential for a deterrence policy based on offensive retaliation, defensive capability, or a combination of both. TW/AA for strategic defenses will be accomplished using the complete suite of SDI sensors tied into the CC/SOIF. These sensors would complement existing and planned systems. For a multilayered SDS, early warning and initial attack assessment would occur in the boost layer. However, later layers—post-boost, midcourse, and terminal—would provide additional sensor information on ballistic missiles or their deployed RVs. This SDS surveillance and tracking capability also will enhance our current offensive-based deterrence posture. TW/AA functions are important in all aspects of defensive operations. The sensors being developed in support of SDI goals could provide similar support to conventional defense elements, aid in the proper assessment of information, and help develop appropriate warning.

Experiments that will support development of SDI tactical warning and attack assessment concepts are described in Chapters 5 and 6 of this report.

Appendix E

SDI Technology Applications

Appendix E

SDI Technology Applications

This appendix provides background information on the SDI Technology Applications Program and Executive and Congressional Direction, and describes the program research areas and activities.

Background

Historically, both the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA) have advanced the state-of-the-art in science and technology and spurred the U.S. economy by transferring technology from military and space programs. Through the various military service research and development agencies, NASA centers, and federal laboratories, significant advances in technology and new inventions have been transferred to both the private and public sectors.

SDI provides such an opportunity because it is redefining what is considered state of the art through the research and development it has initiated in a vast array of new and unexplored areas. From the very beginning, SDIO has maintained the same overall goal—to conduct a vigorous research and technology program that could provide the basis for an informed decision on the feasibility of eliminating the threat posed by ballistic missiles of all ranges. Within that goal, SDIO is working to select from a broad spectrum of capabilities the best technologies which could be used in a strategic defense system (SDS). Technologies currently under investigation include particle beams, kinetic energy interceptors, chemical and free electron lasers, and systems to maintain the SDS if a decision is made to proceed with deployment. The emphasis in this approach has been broad-based SDI research to expand and accelerate the identification, design, and development of relevant technologies for use in the SDS. Because no single or preconceived concept has been identified as the best or most appropriate technology for incorporation into the SDS's design, SDI research is examining a number of concepts that make use of a wide range of technologies.

Because this approach is so broad in its scope, the products and processes generated from SDI research also serve as a source of technological innovations for other private and public sector research and development efforts. SDI research has already, for instance, produced spinoffs in medicine, electronics, optics, computer technology, communications, the transmission of energy, new materials, and advanced industrial processes. SDI technology applications to other defense missions are addressed in Appendix D, SDI Technology and other Defensive Missions.

Executive and Congressional Direction

Recognizing the potential that SDI-developed products and processes have as a source for both private and public sector spinoffs, SDIO, in response to Presidential and Congressional competitiveness and technology transfer initiatives, established a technology applications program designed to make SDI technology available to federal agencies, state and local governments, universities, and business and research interests. These Presidential and Congressional initiatives include the following:

- The Stevenson-Wydler Technology Innovation Act of 1980 established organizations and provided initiatives to stimulate the transfer of technology among federal laboratories and research centers and other federal agencies, state and local governments, colleges and universities, and private persons.
- The Small Business Innovation Development Act of 1982 stimulates technological innovation by using small businesses to meet federal research and development needs and increase the private commercialization of innovations derived from federal research and development. The legislation mandates that federal agencies develop small business innovative research (SBIR) programs and that those agencies establish specific goals for participation of small businesses and minority and disadvantaged organizations in contracts, grants, or cooperative agreements for research and development.
- The Federal Technology Transfer Act of 1986 broadened the scope of the Stevenson-Wydler Technology Innovation Act. The Federal Technology Transfer Act of 1986 seeks to transfer federally funded research to academia, the private sector, and state and local government through greater commercialization of federal research and development efforts.
- Presidential Executive Order 12591, "Facilitating Access to Science and Technology," issued on 27 April 1987, promotes the domestic transfer of technology from the public to the private sectors through such measures as establishing basic science and technology centers, intragovernmental technology-sharing initiatives, and exchange programs for scientists and engineers.

SDIO Technology Applications Program

Building on the foundation laid by Executive and Congressional initiatives, SDIO established the Office of Technology Applications in 1986 to develop and implement a technology applications program designed to make SDI technology available to federal agencies, state and local governments, universities, and U.S. business and research interests. Through this program, SDIO acts as a facilitator to get the right people to talk with each other, i.e., those who have a requirement that can be met with SDI-funded technology and the inventors and developers of that technology. SDIO provides the following services to facilitate this transfer:

- Identifying emerging SDI technologies with potential applications for private and public sector research and development efforts
- Evaluating the commercial potential of SBIR contracts awarded to small businesses and minority and disadvantaged organizations
- Instituting security measures to promote the type of information needed to accelerate the technology spinoffs process while preventing the disclosure of sensitive technology data or intellectual property rights
- Providing U.S. corporations; small businesses; universities; entrepreneurs; and federal, state, and local government agencies with information about these technologies so they can contact the technology inventors and developers.

In providing these services, SDIO uses several tools to encourage person-to-person contact: requirements-pull and technology-push mechanisms of technology transfer. The requirements-pull mechanism is designed to make SDI technology more attractive to those who may use it for other private and public sector requirements. This is done by matching them with a set of technologies that can be integrated or customized to meet those requirements. The technology-push mechanism identifies technologies which have already been developed for SDI and provides the interested party with information on those technologies so they can contact the developers of these emerging SDI technologies to find out if the technologies of interest can be used in the research and development of new products and processes.

Requirements-Pull Features of the SDI Technology Applications Program

The requirements-pull features of the SDI technology applications program stress the importance of networking as a tool to identify potential private sector markets and governmental programs that can use SDI-developed technologies as the basis for private and public sector spinoffs. To accomplish this complex task, SDIO has organized conferences and a network of advisory panels representing industry, professional associations, private research institutes, universities, and federal laboratories and agencies. This network of advisers meets regularly to review technology efforts and identify potential applications of the technology for use in biomedical research, electronics, computer technology, communications, the transmission of power, materials and industrial processes, and military research and development. These advisers constitute the SDIO technology applications committee and panels.

An integral part of the SDI technology applications program is the operation of the technology applications advisory committee. This committee is organized to identify potential applications for SDI technology to the private sector and nonmilitary federal, state, and local government agencies; review the mechanisms by which this transfer takes place; and provide guidance on the overall approach and progress of the technology applications program. The technology applications committee operates as subcommittee under the auspices of the Federal Advisory Committee Act approved SDI Advisory Committee. Members of the committee and panels meet to examine how emerging SDI technologies may be used as a source of technological innovation for private and public sector research and development efforts.

Supporting the technology applications committee are four technology applications panels that advise on the application of SDI technology in specific areas. These panels meet twice a year to examine emerging SDI technologies for their public and private sector applications in biomedical research; electronics, communications, and computer technology; power generation, storage, and transmission; as well as materials and industrial processes.

Members of the technology applications committee and panels, all of whom serve without remuneration except for the reimbursement of their travel and per diem allowances, include representatives from universities, private research institutes, national laboratories, professional associations, industry, and other government agencies. Many of these individuals also hold patents and are nationally known leaders and inventors in their respective fields.

Technology-Push Features of the SDI Technology Applications Program

The technology-push features of the program are built into the development and maintenance of an SDI Technology Applications Information System (TAIS), a data base referral system designed to provide information to interested parties on SDI-developed technologies that may have value and use for the private or public sectors.

The TAIS is accessible by computer modem at no charge to any American corporation or citizen who has complied with DOD certification procedures and signed a binding agreement under penalty of law not to release the requested information to foreign nationals without approval, authorization, or license under U.S. export control laws. The TAIS is also available upon request to all federal agencies.

The TAIS, once accessed, provides its user with more than 1,000 unclassified, nonproprietary abstracts describing SDI-developed technologies and their relationship to generic technologies with potential applications or use to other public and private sector ventures. These abstracts cover SDI research in a broad array of technological areas including superconductivity, sensors, lasers, computer technology, electronics, energy, and materials and industrial processes. The TAIS also provides information on specific federally set-aside research opportunities for SBIR requirements as they apply to SDI; manufacturing technologies needed to support SDI; points of contact at federal, state, and local technology transfer offices and private sector foundations; and accessibility to other technology transfer data bases.

Once the user determines the desired technologies, SDIO works as an intermediary to connect the user with the SDI researcher or developer of those technologies and then tracks the results of that meeting to determine if additional assistance can be provided. In providing such a bridging mechanism between the developer and potential user of the SDI technology, SDIO facilitates the person-to-person contact needed to transfer the technology.

Promising SDI Spinoffs

The SDI technology applications program, through its efforts to accelerate the transfer of SDI-developed technologies to the private and public sectors, has identified promising opportunities where emerging SDI technology could yield spinoffs with a high payoff potential in the near-term. Although such projects are not funded by SDIO, the SDI technology applications program seeks to promote promising SDI technology transfer opportunities by providing the information and encouraging the dialogue needed to build successful partnerships between the inventors and the developers of SDI-funded technologies and those individuals and organizations that can use those technologies in other scientific, technical, and commercial products and processes. Through such collaborative efforts, SDI technologies have yielded public and private sector spinoffs in medicine, electronics, space technology, agriculture, energy, materials and industrial products and processes, and technologies of use to clean and preserve the environment.

SDI Spinoffs in Medicine

SDI research in computer technology, lasers, and materials processes has produced a number of innovations to assist the medical community. This includes developments in the use of lasers in medicine, biomedical research, ophthalmology, eye surgery, and the diagnosis of disease and infection.

Lasers in Medicine and Other Types of Research. A medical free electron laser (MFEL) program was established at the direction of Congress to develop and enhance free electron laser (FEL) technology and assess the FEL's potential application to medical, biophysical, and materials research. MFEL centers for this purpose have been established at Vanderbilt University, Nashville, Tennessee; Stanford University, Palo Alto, California; the University of California at Santa Barbara; Brookhaven National Laboratory, Upton, New York; and the National Institute of Standards and Technology, Gaithersburg, Maryland. The MFEL program is also drawing on the resources and expertise of 21 universities, 2 national laboratories, 2 commercial laboratories, and 1 teaching hospital to support this program.

As a result of an amendment added to the FY 1985 DOD Authorization Act, $10 million was allocated from the SDI budget to create multidisciplinary regional centers to investigate potential applications for the use of FEL technology. Funds allocated from the SDI budget have been increased by $8 million in the past 4 fiscal years to establish the regional MFEL centers and develop the hardware needed for research. The MFEL program has also been chosen as the vehicle to do the following:

- Sponsor MFEL research to be conducted by minority institutions and historically black colleges and universities

- Develop miniaturized, lightweight proton accelerators for position emission tomography (PET), a technique that allows medical researchers to study heart and brain activity, develop new diagnostic techniques, and investigate new drugs.

Areas of Research—SDI research has looked closely at FELs for their potential use as beam interceptors in an SDS against enemy ICBMs. FELs have been the focus of this research because they can achieve higher, more controllable power than conventional lasers and can operate at a wide range of wavelengths. Precision control of power output and pulse structure combine with its tunability to give the FEL unprecedented utility.

It is this utility which makes the FEL so promising as a tool for use in medical, biophysical, and materials research. Because it can operate at such a wide range of wavelengths and power levels, the FEL can be tuned to the desired wavelength needed to cut tissue and bone more effectively than surgical lasers used today. Such characteristics also make the FEL attractive to biophysical and materials research. Because its wavelength can be varied, the FEL can be used by material scientists to probe and study materials for thermal and photochemical reactions and by biophysicists to study the physiological responses of biological materials.

In its effort to find applications for FEL technology in other types of research, the MFEL program has been structured into four components: FEL technology development, and biomedical, biophysical, and materials science research.

Free Electron Laser Technology Development—This component of the MFEL program was initiated to establish and organize university-based multidisciplinary regional FEL centers. Work done in this area of the program includes the necessary competition for the locations, associated research protocols, and the maintenance for the facilities until the site is able to recover the operating costs from users outside the program. Because FEL technology is at the point where further innovation and development are necessary, this segment of the MFEL program seeks out and recommends additional projects to improve FEL reliability and ease of operation and reduce the FEL's physical size and power requirements so it can be used in a clinical setting.

In addition to the work being done at the five regional MFEL centers organized through this component of the MFEL program, other research sites have been established to explore the use of FEL technology in:

- Preclinical medical research, surgical applications, and the diagnosis of disease. This research is being pursued at the Massachusetts General Hospital, Boston, Massachusetts; the University of Utah, Salt Lake City, Utah; Northwestern University, Chicago, Illinois; the Baylor Research Foundation; the University of California at Irvine; and the Uniformed Services University of the Health Sciences, Bethesda, Maryland.
- Biophysics research into medical laser applications at the cellular level. This work is being done at the Baylor Research Foundation;

the Uniformed Services University of the Health Sciences; the University of Michigan at Ann Arbor; Purdue University, Lafayette, Indiana; Princeton University, Princeton, New Jersey; Physical Science, Inc., Andover, Massachusetts.

- Materials science. Investigations in this field are being conducted at the University of Utah; Stanford, Vanderbilt, and Princeton universities; Brown University, Providence, Rhode Island; and the State University of New York at Buffalo.

Biomedical Research—Before the FEL can be approved for use in a clinical environment, many basic light-tissue interaction questions must be answered. In this portion of the MFEL program, research is done to find future medical/clinical application of the FEL. Research is also conducted at medical centers/universities which have a strong background in conventional laser medicine for preclinical uses of the FEL technology for surgery, therapy, and diagnosis of disease.

Biophysical Research—This portion of the MFEL program comprises those projects which investigate the basic mechanism of tunable laser energy sources such as FELs to better understand potential thermal and photochemical change in the biomedical materials to which the lasers are applied. Extensive modeling efforts are under way to develop methodologies to predict the results of light-tissue interactions. Continuous wave thermal models are available for many types of lasers and tissues. Models for pulsed laser-material interactions are in the early stages of investigation as the reaction of many substances to a widely tunable, high-power, short-pulse laser is not well understood.

Materials Science Research—The materials research is targeted for the development of materials needed to build a high power FEL and its associated delivery system. Research for this purpose is being conducted in two areas.

- Due to the very high peak power levels available to FELs, there is a significant problem with mirror damage in the optical cavity and also with the optics associated with delivery systems. This problem becomes increasingly difficult when coupled with the ability to vary wavelength of emitted radiation because various wavelengths require different reflective and refractive materials. One group of researchers is involved in studying mirror damage mechanisms. Delivery systems become increasingly important as the FEL moves from the physicist-only use to that of a biologically oriented use and ultimately to the use of a physician. Evaluation of new fibers or other types of laser light transport systems is being conducted.
- Investigations are being conducted to study the effect of FELs on materials and material processes. Use of tunable, high power, pulsed laser energy can be, for instance, of enormous importance to solid-state physics in the development of new semiconductor materials. Such work will also increase the state of basic knowledge of surface interactions through studies that indicate ways to choose precisely the

parameters necessary to create change in materials and material processes.

Research results from the MFEL program are significant. FEL research sponsored through the MFEL program has yielded a number of breakthroughs, including the following:

- Significant progress has been made in the identification of more than 35 photoactive materials to enhance the use of lasers for photodynamic therapy in the treatment of cancer. The procedure is being investigated to determine if it could also be extended to treatment of heart disease and the prevention of strokes.
- Photodynamic therapy is a process by which a non-toxic photoactive chemical dye is inserted into tissue and absorbed more readily by malignant tissue than by healthy cells. This process lends itself first to the diagnosis and location of tumors, but more importantly to the application of the FEL's tunability and precision power output control.
- A process using a pulsed laser has been developed, approved by the Food and Drug Administration, and is in use at more than a dozen hospitals to fragment kidney stones.
- The clean cutting of bone without charring has been achieved using a FEL. This process has significant promise to simplify and shorten the time for the delicate surgical procedures in joint surgery such as the replacement of fractured hip joints in elderly patients and surgery for acute arthritis.
- Progress in the bone marrow therapy of leukemia and treatment of lymphoma has been enhanced through the use of a photoactive dye which, when retained by malignant tissue, causes the destruction of cancerous cells when exposed to visible laser irradiation without harm to healthy cells.
- The spread of Chagas disease, a parasite-borne infectious disease prevalent in Central and South America, has been abated by the application of a laser induced photodynamic process which has the potential to eradicate the parasitic organism contained in over 5 percent of the blood supply in these Latin American countries.
- Mutant strains of malaria, which took the lives of over a million people around the world last year, can be treated using photoactive hematoporphyrin derivatives to make them again susceptible to the malaria vaccine. Coordination is currently in process with the U.S. Navy to establish a testing program for the methodology.
- The process combining laser angioplasty and balloon angioplasty has been developed by the Uniformed Services University of the Health Sciences to improve the laser angioplasty process' effectiveness and safety in the operating room. Angioplasty is a surgical technique that

removes plaque blockages from blood vessels, the principal cause of heart disease.

- A new technique has been developed where a laser joins tiny blood vessels using the patient's own blood as a bonding agent. This process is called microvessel anasthemosis.
- The entire family of viruses which includes herpes, measles, and the human immunodeficiency viruses I, II, III, IV, and V has been found susceptible to laser-induced photodynamic processes in the presence of absorbed hematoporphyrin derivatives exposed to laser light. Hepatitis B is also affected in a similar manner. The research has evolved a process which could be used to cleanse donor blood supply of the acquired immunodeficiency syndrome. Work is continuing to extend and improve the process using the FEL. Current efforts are being coordinated with the U.S. Navy Blood Laboratory in Boston, Massachusetts, and the American Red Cross Blood Bank Research Center in Rockville, Maryland.
- The susceptibility of white cell lymphocytes to the same type of photodynamic processes makes this method a candidate for the direct treatment of lymphomic leukemia using dialysis-type procedures.
- The new photodynamic process is being looked at by veterinarians for its ability to cleanse harmful viruses from bovine semen so it can be used for artificial insemination. This process is also being applied to the cleansing of calf serum for the production of vaccines.

Biomedical and Rehabilitation Technologies. SDIO and the Department of Veteran Affairs have collaborated on a 6-month study of SDI technology applications for rehabilitation and other biomedical research. The study, prepared by a biomedical engineer from the Department of Veterans Affairs, describes more than 70 opportunities for the use of SDI-derived technology. Included in the report are applications for safer, more efficient medical diagnostic equipment; stronger, lighter weight orthotic braces for paraplegics; new longer lasting and stronger material for prosthetics and implantable devices including artificial heart components; and new biocompatible materials to aid in the treatment and rehabilitation of patients. The study results have been made available to the Department of Veteran Affairs, the National Institute on Disability and Rehabilitation Research, National Rehabilitation Hospital, and other rehabilitation institutions and researchers to stimulate the development of demonstration prototypes for testing and evaluation of these new technologies.

High-Speed Computer Applications in Medicine. High-speed computer processors and programs, developed in part under the SDI Program, are now in use at the Mayo Clinic, Rochester, Minnesota, to model the interaction of potentially new drugs with the human body's chemistry. These technologies also have applications in developing new drugs.

SDI Technology Applications for Ophthalmology and Eye Surgery. SDI optical tracking technologies, laser, and materials research have spawned a number of spinoffs that have applications for ophthalmology and eye surgery. These include the following:

- The tracking of random eye movement for laser surgery. SDI technology for optical tracking of ballistic missiles and warheads and the control of directed energy systems to counter them can be used to track the random movements of the eye. This development will play a critical role in improving the accuracy with which ophthalmologists use lasers in microsurgery on the eye.
- Methods to correct vision. An integrated system of lasers and SDI-derived control software has been proposed as a new concept for correcting visual problems in the eye. The concept uses lasers to measure the abnormalities of the eye and processes the measurements into a precisely controlled laser beam which heats the cornea, allowing it to plastically reshape and thereby correct vision.
- The manufacturing of surgical instruments for eye surgery. The application of diamond crystal coating processes, developed for the protection of optics and coating of electronic circuitry under SDI programs, is being evaluated for producing microminiature instruments for eye surgery and other clinical applications. As a result of SDIO Office of Technology Applications networking and advisers, assistance, a collaborative effort is now under way.

Sensors for Medical Diagnosis. In response to requirements for the development of a very sensitive device for measuring jitter and vibration in SDI space structures, an extremely small, lightweight magneto-hydrodynamic sensor has been developed that measures angular displacement in milliradians. The Department of Transportation is currently using this device built into anthropomorphic dummies in tests designed to assess the mechanisms of neck injury due to rapid head rotation in automobile crashes.

Several varieties of SDI-developed focal plane arrays show great potential for real-time diagnostics in the area of tumor location, abnormal tissue metabolism, anomalous blood flow regions of the skin, and other applications. Small versions are in use in astronomy applications at the Universities of Chicago, Chicago, Illinois; Hawaii, Honolulu, Hawaii; and Wyoming, Laramie, Wyoming, and have been used by astronomers at the University of Arizona, Tucson, Arizona, to locate a previously unknown galaxy. Astronomers using this new technology can now see ten times further out into the universe, expanding man's observable universe by a factor of 1,000.

A gamma ray detector developed by the University of Texas at Dallas for SDI applications has been proposed for adaptation and integration into the scintillation counter portion of the PET camera. This camera can more than double the current resolution of current PET systems.

Medicine and SDI Neutral Particle Beams. Linear accelerator technology developed in response to SDI requirements for a neutral particle beam (NPB) source at

Los Alamos National Laboratory (LANL) has lent itself to both medical and industrial applications. The key element of the technology is a radio frequency quadrupole linear accelerator, known as an RFQ linac. Originally a Soviet concept proposed in 1970, the first RFQ was tested at LANL in 1980. Competition efforts on NPB requirements led to the invention of the precision segment RFQ linac which produced the baseline design for the initial stage of the accelerator in the SDI NPB integrated space experiment. Related supporting technologies—including ion injectors, radio frequency power sources, vacuum pumping systems, water cooling systems, mechanical structures, instrumentation, and controls—have also been pushed by NPB requirements resulting in systems which are compact and more efficient, rugged, and reliable. Actual and projected applications of this technology include the following:

- Cancer therapy applications. Loma Linda University Hospital in Southern California has selected the SDI-derived RFQ linac for use in its proton therapy cancer treatment facility now under construction. It is anticipated that 3 to 5 more facilities using this technology will be built over the next 5 to 10 years.
- Production of radioisotopes for medical diagnosis. The RFQ linac has now been incorporated into the design for a compact proton linac to produce medical radioisotopes for PET via an SBIR grant from the National Cancer Institute. These tracer isotopes are principally used to study and diagnose brain and heart disease. The new technology has produced a smaller, lighter, simpler, and more energy efficient source of radioisotopes than can be safely produced using other methods. Additional medical needs are being assessed for other radioisotopes created by this new technology, and Congress has funded a program within SDI to competitively develop PET proton accelerators to enhance this diagnostic technology.

SDI Spinoffs in Electronics

SDI research has yielded many spinoffs in electronics. These include devices that detect explosives and inspect metallic structures for corrosion; new power sources for medical instrumentation, diagnostic, and therapy devices; and technology to produce new supercomputers and permit the further microminiaturization of electronic circuits.

Devices That Detect Explosives. The NPB RFQ linac technology is applicable for use as a neutron source for non-destructive testing and detection. An SBIR grant has been provided by the Federal Aviation Administration to incorporate the RFQ linac into a high explosive detector for use at airports. The SDIO Office of Technology Applications is working with appropriate offices in the Department of State, the Federal Bureau of Investigation, Department of Justice, U.S. Customs Service, and the Coast Guard regarding this and other technologies for applications to counterespionage, counterterrorism, antisabotage, and law enforcement.

Nondestructive Inspection and the Detection of Corrosion on Metallic Structures. Neutron radiography has been used for many years to examine metallic parts, such as munitions and aircraft structures, for corrosion and internal damage. The compact RFQ linac is especially useful with a new generation of nondestructive inspection equipment because of its small size and portability potential. An SBIR proposal has been approved by the U.S. Navy for integration of the RFQ linac into a system for inspecting rocket motor fuel liners during test firings to detect seal anomalies and potential catastrophic problems. The technology is also applicable to an aircraft inspection system which could detect structural fatigue, corrosion, and other defects. Other applications being suggested by the SDIO Office of Technology Applications include a Department of Transportation application to analysis of potentially dangerous bridge structures in the national highway system.

New Power Sources for Medical Instrumentation, Diagnostic, and Therapy Devices. Progress in the downsizing, weight reduction, and increase in efficiency and capacity of energy storage systems have enabled researchers to develop more portable and efficient lifesaving devices, magnetic resonance imaging facilities, and medical instrumentation for on-site shock-trauma use. Supercapacitors derived from SDI technology at Maxwell Laboratories, San Diego, California, are now, for instance, being used in heart defibrillators and may also have applications in the design of military medical equipment for use on the battlefield.

SDI Technologies and Supercomputer Applications. The Georgia Tech Research Institute, located at the Georgia Institute of Technology, Atlanta, Georgia, has developed very large scale integrated circuit computer technology which combines hardware, computer code, and semiconductor devices for guidance and control simulations of SDI ground-based interceptors. This technology, known as special purpose operational computing kernel (SPOCK), has been licensed for commercial computer applications. The arrangement provides for a royalty to the government on all sales.

SDI Spinoffs and Space Technology

SDI research has been a source of a number of spinoffs that will have applications for satellite technology, energy, and space transportation. Many of these spinoffs have been spawned by SDIO-NASA cooperative research programs and SDI work in space-system technology.

SDIO-NASA Cooperative Research Efforts. SDIO and NASA are already cooperating on a number of programs including the Advanced Launch System, tethered satellites, SP-100 and multimegawatt space power programs, materials, and space structures innovations. Direct spinoffs expected from space power technology include the following:

- Space power applications for direct television broadcasting from satellites which could eliminate the need for television cable or antenna dishes, allowing direct reception using small conventional antennas.
- Remote power for pipeline pumping stations, remote radar sites, undersea habitats, as well as lunar and planetary exploration sites.

- Broad ocean area air traffic control satellites, a program that monitors air traffic over the ocean with space-based radars. This application could save millions of gallons of aircraft fuel as well as shorten travel time.

Space Transportation. The most obvious of spinoffs from SDI space system technologies are those subsystems and innovations that directly translate from one space vehicle to another. The potential for spinoffs in this area includes the following:

- Space Shuttle booster upgrades. A carbon coating process is being used to develop a new fluidic control device for the Shuttle booster engines at significant improvement in cost, weight, and complexity. A high-temperature ceramic probe, inserted into the rocket nozzle exhaust, induces thrust vectoring that can be used in lieu of the current sophisticated gimbal system. This proprietary carbon coating technique, known as the Sullivan process, was originally developed with SDI funds to find a method for extending material properties using a carbon matrix or carbon fiber coating technology.
- Mini thrusters for attitude control. A host of new miniature thruster devices developed for space- and ground-based interceptors is available for application to systems ranging from tactical missiles to satellite control. Associated with the stable of new thrusters and miniature rocket engines are new fuels which are safer, easier to transport, and have an extended shelf or on-orbit life.
- Rail gun satellite launchers. NASA's Jet Propulsion Laboratory is promoting a concept of using SDI-developed electromagnetic gun technology to launch small lightweight satellites the size of tomato cans into low earth orbit . This concept is applicable to launching of large constellations of satellites that could replace single, complex platforms now in use or to restore satellite-monitoring capabilities in wartime. The constellation concept may also prove more efficient, reliable, and inexpensive for many space-science and military-system applications. The same launch technology in a space-based mode could be used for efficiently launching small space probes to explore the outer reaches of the solar system.

SDI Spinoffs and Their Applications for Agriculture

SDI research in laser doppler radars and linear induction accelerator technology have produced spinoffs that have applications for agriculture. Among these are devices that detect the presence of insects harmful to agricultural crops and safer methods to preserve food.

New Instrumentation to Detect Harmful Insects. Laser doppler radar technology derived from an SDI application has led researchers at Oak Ridge National Laboratory to investigate its use to detect and discriminate the presence of various species of insects. Packaged into a small device, this new tool could provide an entirely new and more effective way for entomologists to track and control various species of harmful insects. The U.S. and Mexican departments of agriculture are currently working with the inventor regarding applications of this technology.

Safer Methods to Preserve Food. The Lawrence Livermore National Laboratory (LLNL), Livermore, California, has developed high-power linear induction accelerator technology under an SDI program that can provide a much safer, non-nuclear source to irradiate meats, fruits, vegetables, and other foodstuffs so they can be stored for prolonged periods without spoilage. This same technology can also be used to reduce the need for potentially harmful chemicals used for food treatment.

The Department of Energy is planning to establish food irradiation regional centers which could now choose these safer accelerator-based radiation sources rather than more dangerous and complex radioisotope sources. These centers are being established in Alaska, Florida, Hawaii, Iowa, Oklahoma, and Washington state. At the same time, LLNL is collaborating with the University of California at Davis in a proposed food irradiation research program to evaluate the commercial potential of this linear induction accelerator technology.

SDI Spinoffs in Energy

SDI research in the generation, storage, and transmission of power is providing a technology base for SDI spinoffs with applications to power systems development and energy exploration. Spinoffs from this research include superconducting magnetic energy storage systems and technologies for oil well exploration and drilling.

Superconducting Magnetic Energy Storage. SDIO, in cooperation with the Electrical Power Research Institute, is beginning a 5-year effort to build a superconducting magnetic energy storage (SMES) system. After competitive proposals were solicited, a contract award was made in November 1987. The program has the dual objectives of demonstrating the feasibility of using SMES technology to provide SDI ground power and using the same technology to provide load leveling for commercial electrical utilities. Through these efforts, electrical power utilities will gain an efficient way to level out mismatches that occur between energy supplies and peak demand, store and meter power as required, and reduce fuel consumption and excessive use of other facilities.

Oil Well Exploration. A hemispherical resonator gyroscope (HRG), designed for use in the attitude reference system for a weapons platform, that may eventually be used in oil well drilling heads has been developed. A plan to incorporate HRG technology into a commercial navigation system and plans to conduct flight tests within the next year have also been developed.

Applications of SDI Pulse Power Transmission Technology to Oil Well Drilling. The same basic technology developed for SDI use in control of high energy pulsed power is now being used under a grant from the Department of Energy to fracture and crush rock for drilling oil wells. The new technology represents a substantial advancement in the speed of drilling and control over the drilling process.

SDI technology developed by Tetra for lightweight dielectric pulse-forming lines will play a key part in the development of the commercial drilling machines.

Oil Well Bore Hole Logging. The RFQ linac's compact size may make it useful in fabricating survey tools for oil well logging operations. These tools, once made, could be used in a well shaft and not contaminate the oil field with a dropped radioisotope, a danger inherent with the current procedure. The instrumentation could be used in a bore hole for mineral logging as well.

SDI Spinoffs in Industrial and Materials Products and Processes

SDI research has served as a source of technological innovation for many industrial and materials products and processes. These spinoffs include technologies for chemical analysis; superconducting materials; processes that coat and protect mirrors, electronics, and other devices with thin layers of diamond crystal deposited on their surfaces; optical and electronic devices and technologies for industry; and the development of new materials that have automotive, aerospace, safety and medical applications.

Superconducting Materials and Manufacturing Processes. NASA Langley Research Center, Hampton, Virginia, is currently operating a small wind tunnel which incorporates a magnetic suspension and balancing system (MSBS) using low temperature superconducting material from the niobium family of alloys. This same type of material is also being used in the development of SDI cryogenically cooled superconducting alternators and radio frequency cavity applications for the NPB program. These SDI research and developments will serve as the basis for large-scale MSBS wind tunnel systems to be used by NASA and the U.S. Air Force.

Coupled with the challenge of developing high temperature superconductor materials is the manufacturing process to make them into useful components such as wires, coils, and motor stators and rotors. SDI techniques at the University of California at Los Angeles and the University of Florida, Gainesville, Florida, are also being used to develop manufacturing techniques to make superconducting materials that can be used in electronics, motors, and generators.

Diamond Crystal Coating Technology. Developed under the SDI Diamond Technology Initiative Program for the coating and protection of mirrors, electronics, and other devices in space, this new process for depositing thin layers of diamond crystal on surfaces has numerous applications, such as the following:

- Protection of eyeglasses, windows, and mirrored surfaces
- The hardening of surfaces used for cutting, grinding, manufacturing tools, and machinery
- Magnetic tape head drive and wear protection
- The manufacturing of microminiature surgical instruments from microcircuit technology, coated with diamond crystal to produce super-sharp microsurgical instruments for eye surgery and

angioplasty, a surgical procedure used to unblock blood vessels. A laboratory is being developed at the University of Utah, Salt Lake City, Utah, for this purpose.

Devices and Technologies for Industry. SDI research may serve as a source of numerous spinoffs, devices, and technologies for industry, including the following:

- Linacs derived from SDI technology that could deepen the color of gemstones to enhance their value and harden plastics and other materials for electronic circuit testing and other industrial uses
- Photolithographic processes for microfluidic devices with applications in industry, medicine, computers, automobiles, and aerodynamics
- High-power density alkaline fuel cells which can use ambient air instead of exotic fuels and are adaptable to long-term power needs at remote sites or for backup systems
- Monolithic solid oxide fuel cells with no moving parts that can use gasoline, jet fuel, and methane gas with efficiencies twice that of conventional automobile engines
- High-temperature electromagnetic spectral windows to allow monitoring and control of ceramics, steel, and other high-temperature manufacturing processes
- Multilayer ceramic processing techniques that can combine in one material the characteristics of electrical, thermal, and mechanically active properties
- Supercapacitors with over 20 times the capacity or energy storage capability of current technology
- Attentive associative memory software which permits a high degree of artificial intelligence self-programming capability for computers
- Cryogenic alternators which provide a 40-percent increase in power output per unit weight and are more simple, reliable, and inexpensive than current devices
- High-power super batteries which may be used as lightweight, more powerful energy sources for car batteries
- Superconductor materials with applications for superfast computers, low power electronics and appliances, as well as transportation systems
- Hypercube parallel processing techniques for high-speed, large-scale computing applications such as weather prediction and FAA air traffic control programs
- Advanced thermoelectric cell for conversion of heat to electrical power

- Stacked platelet manufacturing technology for rocket motor and random cooling technology applied to carburetors and fuel injectors, fluidic control for more efficient heating and cooling devices, ceramic automobile engines, and electronic devices.

While many of these technologies are in the prototype or developmental stage, they promise to provide a significant advancement of the technology base in many areas.

New Materials With Automotive, Aerospace, Safety, and Medical Applications. The Sullivan process, a method for extending material properties using a carbon matrix and/or carbon fiber coating technology originally investigated under an SDI SBIR contract, is being evaluated for use in a number of automotive, turbine engine, safety, and medical applications. Evaluations in progress include applications of the high temperature, carbon fiber reinforced ceramic materials for automobile gasoline and diesel-engine components such as turbosuperchargers, jet engine turbine blades, protective garments, and surgical gloves. SDIO, working through the American Automobile Manufacturers Association and others, has assisted the small business in a number of ways. For example:

- Tests are being completed on Sullivan process-derived ceramic roller cam followers for four cylinder overhead cam engines. We are also investigating other similar components for introduction in upcoming models.
- A team from the United Kingdom has signed a teaming agreement with the inventor of the Sullivan process for carbon fiber reinforced ceramic materials to be used in gas turbines.
- American automobile manufacturers will test composite automobile suspension components intended to dampen vehicular vibrations and noise made from Sullivan process-derived materials.
- An agreement has been signed to evaluate proprietary materials for an aircraft engine application.
- Testing on a Sullivan process-derived material for automobile and aircraft brake systems is being conducted.
- Sulphur Springs, Texas, is negotiating a licensing agreement with Sullivan to manufacture asphalt stripper machine teeth and other devices for its fleet of construction equipment.
- Memphis, Tennessee, is evaluating an application of the Sullivan process in the manufacture of microsurgical instruments for eye surgery.
- Vanderbilt University is cooperating with Sullivan in the design and fabrication of a prototype endotracheal tube which is nonflammable. This will reduce the chance of fire hazard during laser surgery, preventing a repeat of cases where endotracheal tubes currently in use have accidently caught on fire during laser larynx surgery.

- A leading manufacturer of prosthetics is investigating a durable ceramic material derived from the Sullivan process for carbon fiber reinforced ceramics to manufacture the ball joint in hip joint replacements.
- The Sullivan process may also be used to make flexible, tactile protective surgical gloves. The hazards of self-inflicted hand wounds, wounds from bone shards during surgery, or wounds encountered during surgical removal of sharp-edged shrapnel from patients in the potentially infectious environment brought about by AIDS make such protection for surgeons a necessity. Gloves and finger costs of this material are currently under evaluation by U.S. Air Force Wilford Hall Medical Center, Lackland AFB, Texas, and U.S. Army Medical Research and Development Command's Combat Casualty Care Research Center, Ft. Detrick, MD. The gloves are also under evaluation by the Human Systems Division, Brooks AFB, San Antonio, Texas, and the U.S. Army Natick Laboratory for Bio-Chemical Defense Applications, Natick, Massachusetts.

SDI Technologies and Protection and Cleanup of the Environment

SDI technologies have been developed that may have use in protecting and cleaning up the environment. SDI technologies may, for instance, be of use in the development of coolers and compressors to help preserve the earth's ozone layer, accelerator uses to combat acid rain, assay and dispose of nuclear waste, treat sewage, and clean up toxic waste.

Coolers and Compressors to Protect the Ozone Layer. A new high efficiency, large displacement rotary vane compressor developed by Orlando, Florida, to meet cryogenic needs for space systems is currently being investigated for use in automotive air conditioners. The compressor may allow for further use of nonhazardous fluorocarbon refrigerants, thus reducing the need for chlorofluorocarbon refrigerants which have been cited for their environmental degradation of the ozone layer. The new compressor may also be of use in refrigerators, heat pumps, and decompression pumps designed for use in the space station's air locks.

A similar spinoff is being pursued by Boulder City, Nevada, to develop a heat pump technology which, instead of replacing fluorocarbons, uses ammonia, water, or alcohols in various heating and cooling cycle applications. The company is currently developing an ammonia system for Chicago, Illinois, based on SDI-derived heatpump technology for space defense systems and is working with thermal storage equipment manufacturers to use this technology for similar purposes.

SDI Technologies to Combat Acid Rain. Scientists at LLNL are proposing using new, efficient SDI-derived accelerators to bombard sulphur and nitrogen oxide compounds in power plant smoke in order to change their composition and render them not only harmless to the environment, but also produce a byproduct which can be used as fertilizer. Laboratory tests have shown that 90 to 100 percent of the acid forming flue gases can be removed using the electron beam technique. Though the feasibility of this approach has been demonstrated with earlier, less efficient accelerators, the new technology brings more cost-effective technology to bear on the problem. The same technology can also be used to treat sewage and sterilize medical equipment.

The Assay and Disposal of Nuclear Waste. The SDI-derived RFQ linac may be used as the neutron source for incorporation into equipment that detects concentration of nuclear waste material, so technicians can dispose of the waste materials. The RFQ linac is also being considered for a process that changes the nuclear waste material's nuclear structure, so that it decays more quickly and is rendered harmless sooner. Use of this concept could potentially eliminate the need to dispose of the harmful waste materials by burying it. These techniques also apply to treating sewage and cleaning up toxic waste.

Manufacturing Technology for Automotive Pollution Control. SDI-funded research to improve the platelet manufacturing technology for rocket thrusters holds promising potential for use in the manufacturing high-efficiency carburetors. Spinoffs from this development include fluidic control devices and more efficient automobile carburetors and fuel injector systems that could potentially eliminate the need for catalytic converters designed to reduce automobile emissions.

Summary

The spinoffs discussed in this section are a small sample of the technologies developed through SDI research that can serve as a source of scientific and technological innovations for products and processes with an impact on the private and public sectors. Though SDI's primary goal is to ensure and enhance U.S. nuclear deterrence by providing the technologies needed to develop an SDS against enemy ICBMs, research conducted for this purpose also holds the promise and reality of private and public sector spinoff opportunities to benefit the U.S. economy and improve its productivity and competitiveness in the world marketplace.

List of Acronyms

List of Acronyms

ABE	Army Background Experiment
ABM	Antiballistic Missile
ACE	Advanced Component Evaluation
ADCOM	(U.S.) Aerospace Defense Command
ADI	Air Defense Initiative
ADOP	Advanced Digital Operations Processor
AGT	Aboveground Test
AJ	Antijam
AJPO	Ada Joint Program Office
ALE	Airborne Laser Experiment
ALS	Advanced Launch System
AMOS	Air Force Maui Optical Station
AMTL	Army Materials
ANMCC	Alternate National Military Command Center
AOA	Airborne Optical Adjunct
AOS	Airborne Optical System
AOSP	Advanced On-Board Signal Processor
ASAT	Antisatellite
ASM	Antisimulation Antiship Missile
ASSH	Advanced Space Systems Hardening
ATA	Advanced Test Accelerator
ATB	Allied Test Bed
ATBM	Antitactical Ballistic Missile
ATM	Antitactical Missile
ATP	Acquisition, Tracking, and Pointing
ATP-FC	Acquisition, Tracking, and Pointing and Fire Control
ATS	Accelerator Test Stand
AWACS	Airborne Warning and Control System
BCD	Baseline Concept Description

BCS	Beam Control System
Be	Beryllium
BEAR	Beam Experiment Aboard Rocket
BGV	Boost Glide Vehicle
BIB	Blocked Impurity Band
BM/C^3	Battle Management/Command, Control, and Communications
BMD	Ballistic Missile Defense
BMT	Ballistic Missile Threat
BPX	Battle Plan Execution
BSE	Boresight Error
BSEC	Boresight Error Compensation
BSTS	Boost Surveillance and Tracking System
BTI	Balanced Technology Initiative
C^3	Command, Control, and Communications
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CC	Command Center
CCM	Counter Countermeasure
CC/SOIF	Command Center/System Operation and Integration Functions
CDI	Conventional Defense Initiative
CDR	Critical Design Review
CIM	Computer-Integrated Manufacturing
CINC	Commander-in-Chief
CINCEUR	Commander-in-Chief, Europe
CINCLANT	Commander-in-Chief, Atlantic
CINCPAC	Commander-in-Chief, Pacific
CINCSAC	Commander-in-Chief, Strategic Air Command
CINCSPACE	Commander-in-Chief, U.S. Space Command
CIRRIS	Cryogenic Infrared Radiance Instrumentation for Shuttle
CM	Countermeasures
CMEST	Cruise Missile Engagement Systems Technology
CMOS	Complementary Metal Oxide Semiconductor

COEA	Cost and Operational Effectiveness Analysis
CONUS	Continental United States
CPSU	Communist Party, Soviet Union
CPU	Central Processing Unit
CRO	Chemical Release Observation
CSO	Closely Spaced Object
CSS	Cooperating Space System
CTV	Control Test Vehicle
CV	Carrier Vehicle
CWDD	Continuous Wave Deuterium Demonstrator
DAASAT	Direct Ascent Antisatellite
DAB	Defense Acquisition Board
DANASAT	Direct Ascent Nuclear Antisatellite
DARPA	Defense Advanced Research Projects Agency
DARPANET	DARPA Communications Network
DASO	Demonstration and Shakedown Operation
DATE	Decision Aid Test Environment
DDR&E	Director, Defense Research and Engineering
DE	Directed Energy
DEFCON	Defense Condition
Dem/Val	Demonstration/Validation
DEW	Directed Energy Weapon(s)
DIA	Defense Intelligence Agency
DIPS	Dynamic Isotope Power System
DNA	Defense Nuclear Agency
DOD	Department of Defense
DOE	Department of Energy
DOT&E	Director, Operational Test and Evaluation
DPP	Distributed and Parallel Processing
DRB	Defense Resources Board
DSAT	Defense Satellite
DSB	Defense Science Board

DSD	Defensive Shields Demonstration
DSP	Defense Support Program
DST	Defense Suppression Threat
DTL	Drift Tube Linac
DTST	Defense Technologies Study Team
EADTB	Extended Air Defense Test Bed
EADTP	Extended Air Defense Test Program
ECCM	Electronic Counter-Countermeasures
ECM	Electronic Countermeasures
EDX	Exoatmospheric Discrimination Experiment
EHF	Extremely High Frequency
EIAP	Environmental Impact Analysis Process
EIS	Environmental Impact Statement
ELSI	Enhanced Longwave Spectrometer Imager
EMG	Electromagnetic Gun
EML	Electromagnetic Launcher
EMP	Electromagnetic Pulse
ENSS	Experimental Network Surveillance System
EPA	Environmental Protection Agency
EPSAT	Environment - Power System Analysis Tool
ERINT	Extended Range Interceptor Technology
ERIS	Exoatmospheric Reentry Vehicle Interceptor Subsystem
ESD	Electronic Systems Division
ETM	Engineering Test Model
EV	Experimental Version
EW	Electronic Warfare
EW/AA	Early Warning and Attack Assessment
FAA	Federal Aviation Administration
FBB	Fast Burn Booster
FEL	Free Electron Laser
FET	Field Effect Transistor
FLAGE	Flexible Lightweight Agile Guided Experiment

FMB	Financial Management Board
FOC	Full Operating Capability
FOT&E	Follow-on Test and Evaluation
FOV	Field of View
FPA	Focal Plane Array
FSD	Full-Scale Development
FTV	Functional Test Vehicle
FY	Fiscal Year
FYP	Five-Year Plan
GaAs	Gallium Arsenide
GAO	General Accounting Office
GBEV	Ground-Based Experimental Version
GBFEL	Ground-Based Free Electron Laser
GBI-X	Ground-Based Interceptor - Exoatmospheric
GBL	Ground-Based Laser
GBMI	Ground-Based Midcourse Interceptor
GBR	Ground-Based Radar
GBR-X	Ground-Based Radar - Experimental
GEP	Ground Entry Point
GES	Ground Engineering System
GFLOP	Giga (Billion) Floating Point Operations
GSTS	Ground-Based Surveillance and Tracking System
GTA	Ground Test Accelerator
GVSC	Generic VHSIC Spaceborne Computer
HDA	Hybrid Detection Assembly
HEDI	High Endoatmospheric Defense Interceptor
HEL	High-Energy Laser
HELSTF	High-Energy Laser Systems Test Facility
HEMP	High-Altitude Electromagnetic Pulse
HF	High Frequency Hydrogen Fluoride
HgCdTe	Mercury Cadmium Telluride

HIT	Heterojunction Interface Trap
HOE	Homing Overlay Experiment
HPM	High-Power Microwave
HTS	High Temperature Superconducting
HVG	Hypervelocity Gun
HVP	Hypervelocity Projectile
HWIL	Hardware-in-the-Loop
HYWAYS	Hybrids With Advanced Yield for Surveillance
IAT	Integrated Assembly Test
IBC	Impurity Band Conduction
IBSS	Infrared Background Signature Survey
ICBM	Intercontinental Ballistic Missile
ID	Interactive Discrimination
IED	Intrinsic Event Discrimination
IEV	Integrated Experimental Version
IFOG	Interferometer Fiber Optic Gyro
OV	Instantaneous Field of View
IG	Inspector General
IISE	Insure Integrated Survivability Experiments
ILS	Integrated Logistics and Support
ILSMT	ILS Management Teams
ILSP	Integrated Logistics Support Plans
IMC	Internal Management Control
IMCR	Internal Management Control Review
IMU	Inertial Measurement Unit
INF	Intermediate Range Nuclear Forces
IOC	Initial Operating Capability
IR	Infrared
IRBM	Intermediate-Range Ballistic Missile
IRM	Information Resources Management
IRR	Interim Requirements Review
ISE	Integrated Space Experiment

IST	Innovative Science and Technology
IS&T	Invite, Show, and Test
ISWG	Integrated Support Working Group
IV	Interceptor Vehicle
IWCD	Integrated Wavefront Control Demonstration
JCS	Joint Chiefs of Staff
JDAI	Joint SDI-Defense Technology Applications Initiative
JSTPS	Joint Strategic Target Planning Staff
KBSF	Knowledge-Based Sensor Fusion
KDEC	Kinetic Energy Digital Emulation Center
KDS	Kwajalein Discrimination System
KE	Kinetic Energy
KEW	Kinetic Energy Weapon(s)
KHIL	Kinetic Hardware-in-the-Loop
KHIT	Kinetic Hover Interceptor Test
KKV	Kinetic Kill Vehicle
KMR	Kwajalein Missile Range
KREMS	Kiernan Reentry Measurements System
LACE	Laser Atmospheric Compensation Experiment
LAMP	Large Advanced Mirror Program
LANL	Los Alamos National Laboratory
LASE	LIDAR Acquisition and Sizing Experiment
LASERCOM	Laser Communications
LDS	Lexington Discrimination System
LEAP	Lightweight Exoatmospheric Projectile
LEO	Low Earth Orbit
LFOV	Large Field of View
LICD	Laser Imaging Component Development Program
LIDAR	Light Detection and Ranging
LHX	Light Helicopter Experimental
LINAC	Linear Acceleration
LLNL	Lawrence Livermore National Laboratory

LNA	Low Noise Amplifier
LOC	Lines of Code
LODE	Laser Optics Demonstration Experiment
LOWKATER	Low Weight KEW Active Tracker
LPAR	Large Phased-Array Radar
LRINF	Longer-Range Intermediate Nuclear Forces
LSA	Logistics Support Analysis
LTH	Lethality and Target Hardening
LWIR	Long-Wavelength Infrared
ManTech	Manufacturing Technology
MaRV	Maneuvering Reentry Vehicle
MCS	Midcourse Sensor(s)
MCSS	Midcourse Sensor Study
MCTR	Missile Control Technology Regime
MEO	Medium Earth Orbit
MFEL	Medical Free Electron Laser
MHD	Magneto-Hydrodynamics
MIG	Micro Optic Integrated Gyroscope
MILSAT	Military Satellite
MIPS	Million Instructions Per Second
MIRV	Multiple Independently Targetable Reentry Vehicle
MMW	Millimeter Wave
MODIL	Manufacturing, Operations, Development, and Integration Laboratory
MOS	Metal Oxide Semiconductor
MOSHED	Multiplanar Organic Scintillator High Energy Detector
MOU	Memorandum of Understanding
MRBM	Medium-Range Ballistic Missile
MRDA	Mission Requirements and Definition Analysis
MS	Milestone
MSX	Midcourse Sensor Experiment
MT	Megaton

MV	Miniature Vehicle
MWIR	Medium-Wavelength Infrared
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards
NCA	National Command Authorities
NDEW	Nuclear Directed Energy Weapons
NEI	Noise Equivalent Input
NEV	Network Experimental Version
NHMT	Nuclear-Hardened Mosaic Technology
NMCC	National Military Command Center
NNK	Non-Nuclear Kill
NORAD	North American Aerospace Defense (Command)
NPB	Neutral Particle Beam
NPG	Nuclear Planning Group
NRL	Naval Research Laboratory
NSA	National Security Agency
NSDD	National Security Decision Directive
NSSC	National Space Surveillance Center
NSTE	Near-Term System Integration Test and Evaluation
NTB	National Test Bed
NTF	National Test Facility
OAMP	Optical Airborne Measurement Program
OASP	On-Array Advanced Signal Processing
OMT	Other Military Targets
ONR	Office of Naval Research
OPINE	Operations in Nuclear Environment
OSD	Office of the Secretary of Defense
OSDR&E	Office of the Secretary of Defense for Research and Engineering
OTH	Over-the-Horizon
OTH-B	Over-the-Horizon Backscatter

OTO	Operational Test Organization
PACOSS	Passive and Active Controls of Space Structures
PAR	Phased-Array Radar
PAS	Producibility/Affordability/Supportability
PATHS	Precursor Above the Horizon Sensor
PBV	Post-Boost Vehicle
PDR	Preliminary Design Review
PE	Program Element
PEO	Program Executive Officer
PFC	Prototype Flight Cryocooler
P^3I	Preplanned Product Improvement
PIMS	Programmable Implantable Medication System
PM	Program Manager
POM	Program Objective Memorandum
PPBS	Programming, Planning, and Budgeting System
QM	Queen Match
RADC	Rome Air Development Center
RAM	Random Access Memory Reliability, Availability, Maintainability
RB	Reentry Body
RCS	Radar Cross Section
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
REC	Radio Electronic Combat
RF	Radio Frequency
RFOG	Resonant Fiber Optic Gyro
RFP	Request for Proposal
RFQ	Radio Frequency Quadripole Request for Quote
RH32	Radiation-Hardened 32-Bit Microprocessor
RISC	Reduced Instruction Set Computer
RME	Relay Mirror Experiment
ROE	Rules of Engagement

RTIM	Radar Technology Identification Methodology
RV	Reentry Vehicle
SA/BM	Systems Analysis/Battle Management
SAE	Service Acquisition Executive
SALT	Strategic Arms Limitation Talks
SAM	Surface-to-Air Missile
SAMS	Space Assembly and Maintenance Study
SAMTO	Space and Missile Test Organization (USAF)
SAPPE	Solar Array Performance in Plasma Environments
SATKA	Surveillance, Acquisition, Tracking, and Kill Assessment
SBES	Space-Based Experimental System
SBEV	Space-Based Experimental Version
SBI	Space-Based Interceptor
SBI-CV	Space-Based Interceptor Carrier Vehicle
SBIR	Small Business Innovative Research
SBL	Space-Based Laser
SBR	Space-Based Radar
SC	Software Center
SCOE	Software Center of Excellence
SCOPA	Survivable Concentrating Photovoltaic Array
SCP	System Concept Paper
SDC	Strategic Defense Commander (USA)
SDI	Strategic Defense Initiative
SDIAE	Strategic Defense Initiative Acquisition Executive
SDIO	Strategic Defense Initiative Organization
SDR	System Design Review
SDS	Strategic Defense System
SEER	Sensor Experiment Evaluation and Review
SEI	Software Engineering Institute
SE&I	Systems Engineering and Integration
SEO	Survivability Enhancement Option
SEU	Single Event Upset

Si	Silicon
SIE	SATKA Integrated Experiment
SIOP	Single Integrated Operations Plan
SLBD	Sealite Beam Director
SLBM	Submarine-Launched Ballistic Missile
SLIM	Scanning Long-Wavelength Infrared Module
SLKT	Survivability, Lethality, and Key Technologies
SMES	Superconducting Magnetic Energy Storage
SNF	Strategic Nuclear Forces
SOI	Silicon-on-Insulator
SOIF	System Operation and Integration Functions
SOS	Silicon-on-Sapphire
SPACECOM	Space Command (USAF)
SPADATS	Space Detection and Tracking System
SPADOC	Space Defense Operations Center
SPAS	Space Power Architecture Study
SPEAR	Space Power Experiments Aboard Rockets
SPO	System Program Office
SPOCK	Special Purpose Operating Computer Kernel
SRBM	Short-Range Ballistic Missile
SRF	Strategic Rocket Force
SRINF	Short-Range Intermediate Nuclear Forces
SRMP	Sounding Rocket Measurement Program
SRR	System Requirements Review
SRT	Strategic Red Team
SSBN	Ballistic Missile Submarine (Nuclear)
SSGM	Strategic Scene Generation Model
SSN	Submarine (Nuclear)
SSPM	Solid-State Photomultiplier
SSTS	Space-Based Surveillance and Tracking System
S&T	Science and Technology
STA	Significant Technical Accomplishments

STARS	Software Technology for Adaptable, Reliable Systems
START	Strategic Arms Reduction Talks
STAS	Space Transportation Architecture Study
STM	Significant Technical Milestone
SUPER	Survivable Solar Power Subsystem Demonstrator
SWIR	Short-Wavelength Infrared
TAD	Tactical Air Defense
TAIS	Technology Applications Information Systems
TBM	Theater Ballistic Missile
TCE	Three-Color Experiment
TDSSPA	Technology Development for Solid-State Phased Arrays
T&E	Test and Evaluation
TEMP	Test and Evaluation Master Plan
TEWG	Test and Evaluation Working Group
THAAD	Tactical High Altitude Area Defense
TIE	Technology Integration Experiment
TIR	Terminal Imaging Radar
TMD	Theater Missile Defense
TMDAS	Theater Missile Defense Architecture Studies
TOM	Threat Object Map
T/R	Transmit/Receive
TVE	Technology Validation Experiment
TW/AA	Tactical Warning/Attack Assessment
TWT	Traveling Wave Tube
UGT	Underground Test
UKAS	United Kingdom Architecture Study
USAAE	U.S. Army Acquisition Executive
USAKA	U.S. Army Kwajalein Atoll
USSPACECOM	U.S. Space Command
UV	Ultraviolet
VHSI	Very High-Speed Integration
VHSIC	Very High-Speed Integrated Circuit

VIS/UV	Visible/Ultraviolet
VLOS	Vertical Line of Sight
VLSIC	Very Large-Scale Integrated Circuit
VUE	Visible/Ultraviolet Experiment
WESTPAC	Western Pacific
WFOV	Wide Field of View
WSMR	White Sands Missile Range
WTA	Weapon Target Assignment
XRL	X-Ray Laser
YESKD	Unified System of Design Documentation (Soviet)

Glossary

Glossary

Acquisition—The process of searching for and detecting a potentially threatening object in space. An acquisition sensor is designed to search a large area of space and to distinguish potential targets from other objects against the backdrop of space.

Algorithms—Rules and procedures for solving a problem.

Antiballistic Missile System—A missile system designed to intercept and destroy a strategic offensive ballistic missile or its reentry vehicles.

Antisatellite Weapon—A weapon designed to destroy satellites in space. The weapon may be launched from the ground or an aircraft or be based in space. The target may be destroyed by nuclear or conventional explosion, collision at high speed, or directed energy beam.

Architecture—Description of all functional activities to be performed to achieve the desired level of defense, the system elements needed to perform the functions, and the allocation of performance levels among those system elements.

Ballistic Missile—A guided vehicle propelled into space by rocket engines. Thrust is terminated at a predesignated time after which the missile's reentry vehicles are released and follow free-falling trajectories toward their ground targets under the influence of gravity. Much of a reentry vehicle's trajectory will be above the atmosphere.

Battle Management—A function that relies on management systems to direct target selection and fire control, perform kill assessments, provide command and control, and facilitate communications.

Boost—The first portion of a ballistic missile trajectory during which it is being powered by its engines. During this period, which usually lasts 3 to 5 minutes for an ICBM, the missile reaches an altitude of about 200 km whereupon powered flight ends and the missile begins to dispense its reentry vehicles. The other portions of missile flight, including midcourse and reentry, take up the remainder of an ICBM's flight time of 25 to 30 minutes.

Booster—The rocket that propels the payload to accelerate it from the earth's surface into a ballistic trajectory, during which no additional force is applied to the payload.

Brightness—The unit used to measure source intensity. To determine the amount of energy per unit area on target, both source brightness and source-target separation distance must be specified.

Bus—Also referred to as a post-boost vehicle, it is the platform on which the warheads of a single missile are carried and from which warheads are dispensed.

Carrier Vehicle (CV)—A space platform whose principal function is to house the space-based interceptors in a protective environment prior to use.

Chaff—Strips of frequency-cut metal foil, wire, or metalized glass fiber used to reflect electromagnetic energy, usually dropped from aircraft or expelled from shells or rockets as a radar countermeasure.

Chemical Laser—A laser in which a chemical action is used to produce pulses of intense light.

Communication—Information or data transmission between two or more ground sites, between satellites, or between a satellite and a ground site.

Decoy—A device constructed to simulate a nuclear-weapon-carrying warhead. The replica is less costly and much less massive; it can be deployed in large numbers to complicate enemy efforts to read defense strategies.

Directed Energy—Energy in the form of atomic particles, pellets, or focused electromagnetic beams that can be sent long distances at, or nearly at, the speed of light.

Directed Energy Device—A device that employs a tightly focused and precisely directed beam of very intense energy, either in the form of light (a laser) or in the form of atomic particles traveling at velocities at or close to the speed of light (particle beams). (See also Laser.)

Discrimination—The process of observing a set of attacking objects and differentiating between decoys or other nonthreatening objects and actual threat objects.

Electromagnetic Gun—A gun in which the projectile is accelerated by electromagnetic forces rather than by an explosion as in a conventional gun.

Endoatmospheric—Within the earth's atmosphere, generally considered to be at altitudes below 100 kilometers.

Engagement Time—The amount of time that a weapon platform takes to negate (destroy or incapacitate) a given target. This includes not only firing at the target, but all other necessary weapon functions involved that are unique to that particular target.

Excimer Laser—Also called "excited dimer" laser, which uses the electrically produced excited states of certain molecules such as rare gas halides (which produce electromagnetic radiation in the visible and near ultraviolet part of the spectrum).

Exoatmospheric—Outside the earth's atmosphere, generally considered to be at altitudes above 100 kilometers.

Exoatmospheric Reentry Vehicle Interceptor Subsubsystem (ERIS)—The original name that refers to the Lockheed variant of a ground-based interceptor (GBI) that could be used in a strategic defense system.

Fluence—The amount of energy per unit area on target. (It should be specified whether this is incident or absorbed fluence.)

Gamma Ray—Electromagnetic radiation resulting from nuclear transitions.

Ground-Based Interceptor (GBI)—The generic name for a ground-based interceptor, such as ERIS.

Ground Entry Point (GEP)—The point where sensor data and other information are received by a ground station.

Hardening—Measures which may be employed to render military assets less vulnerable.

Hypervelocity Gun (HVG)—A gun that can accelerate projectiles to 5 kilometers per second or more; for example, an electromagnetic or rail gun.

Imaging—The process of identifying an object by obtaining a high quality image or profile of it.

Interception—The act of destroying a moving target.

Intercontinental Ballistic Missile (ICBM)—A land-based ballistic missile with a range greater than 3,000 nautical miles.

Intermediate-Range Ballistic Missile (IRBM)—A land-based ballistic missile with a range of 500 to 3,000 nautical miles.

Kinetic Energy—The energy from the motion of an object.

Kinetic Energy Interceptor—An interceptor that uses a nonexplosive projectile moving at very high speed to destroy a target on impact. The projectile may include homing sensors and on-board rockets to improve its accuracy, or it may follow a preset trajectory (as with a shell launched from a gun).

Laser (Light Amplification by the Stimulated Emission of Radiation)—A device for producing an intense beam of coherent light. The beam of light is amplified when photons (quanta of light) strike excited atoms or molecules. These atoms or molecules are thereby stimulated to emit new photons (in a cascade or chain reaction) which have the same wavelength and are moving in phase and in the same direction as the original photon. A laser may destroy a target by heating, melting, or vaporizing its surface.

Layered Defense—A defense that consists of several layers that operate at different portions of the trajectory of a ballistic missile. Thus, there could be a first layer (e.g., boost) of defense with remaining targets passed on to succeeding layers (e.g., midcourse, terminal).

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Leakage—The percentage of intact and operational warheads that get through a defensive system.

Lethality—State of effectiveness of an amount of energy or other beam characteristic required to eliminate the military usefulness of enemy targets by causing serious degradation or destruction of a target system.

Midcourse—That portion of the trajectory of a ballistic missile between boost/post-boost and reentry. During this portion of the missile trajectory, the target is no longer a single object but a swarm of RVs, decoys, and debris falling freely along preset trajectories in space.

Multiple Independently Targetable Reentry Vehicle (MIRV)—A package of two or more reentry vehicles which can be carried by a single ballistic missile and guided to separate targets. MIRVed missiles employ a warhead-dispensing mechanism called a post-boost vehicle which targets and releases the warheads.

Neutral Particle Beam (NPB)—An energetic beam of neutral atoms (no net electric charge). A particle accelerator accelerates the particles to nearly the speed of light.

Non-Nuclear Kill—Destruction that does not involve a nuclear detonation.

Particle Beam—A stream of atoms or subatomic particles (electrons, protons, or neutrons) accelerated to nearly the speed of light.

Particle Beam Device—A device that relies on the technology of particle accelerators (atom smashers) to emit beams of charged or neutral particles which travel near the speed of light. Such a beam could theoretically destroy a target by several means, e.g., electronics upset, electronics damage, softening/melting of materials, sensor damage, and initiation of high explosives.

Passive Sensor—A sensor that detects only radiation naturally emitted (infrared radiation) or reflected (sunlight) from a target.

Penetration Aid—A device, or group of devices, that accompanies a reentry vehicle during its flight to spoof or misdirect defenses and thereby allow the RV to reach its target.

Post-Boost—The portion of a missile trajectory following boost and preceding midcourse.

Post-Boost Vehicle (PBV)—The portion of a missile payload that carries the multiple warheads and has maneuvering capability to place each warhead on its final trajectory to a target. (Also referred to as a "bus.")

Rail Gun—A device using electromagnetic launching to fire hypervelocity projectiles. Such projectile launchers will have very high muzzle velocities, thereby reducing the lead angle required to shoot down fast objects.

Reentry Vehicle (RV)—The part of a ballistic missile that carries the nuclear warhead to its target. The RV is designed to reenter the earth's atmosphere in the terminal portion of its trajectory and proceed to its target.

Responsive Threat—A threat that has been upgraded in quality or quantity or with added protective countermeasures in response to a projected capability of defeating (all or part of) the threat.

Sensor—A device that detects and/or measures certain types of physically observable phenomena.

Signature—The characteristic pattern of the target observed by detection and identification equipment.

Surveillance—An observation procedure that includes tactical observations, strategic warning, and meteorological assessments, by optical, infrared, radar, and radiometric sensors on spaceborne and terrestrial platforms.

Survivability—The capability of a system to avoid or withstand hostile environments without suffering irreversible impairment of its ability to accomplish its designated mission.

Terminal—The final portion of a ballistic missile trajectory during which warheads and penetration aids reenter the atmosphere. This follows midcourse and continues until impact or detonation.

Tracking and Pointing—Once a target is detected, it must be followed or "tracked." When the target is successfully tracked, an interceptor, laser, or neutral particle beam is "pointed" at the target. Tracking and pointing are frequently integrated operations.

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